Design for Internet of Things
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Lecture - 43
IEEE 802.15.4e – 01

All right, so let us take up one more wireless protocol, which is quite, I would say, famous in the IoT world. The best way to understand this protocol is to see what is around in the market. So just to help you a little bit, I went to this website.

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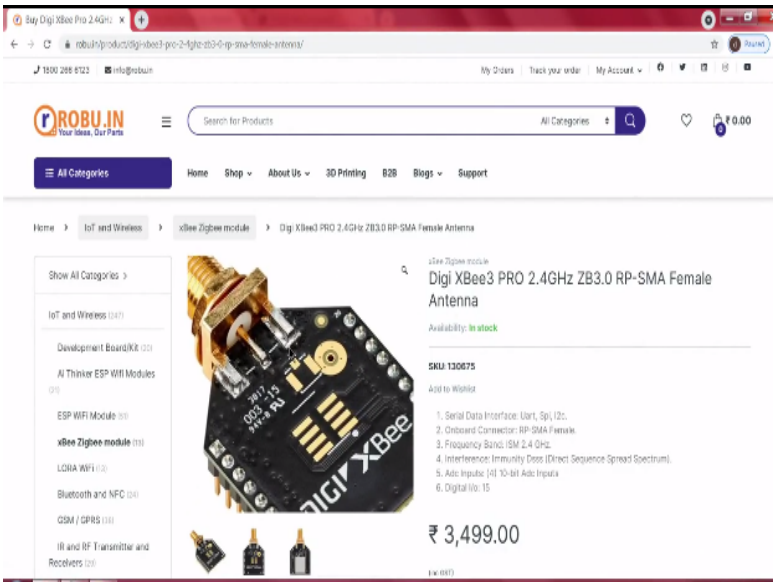

This is the ROBU.IN website and I looked up this module, okay. This module is just I mean randomly I picked this module. It is called Digi XBee module, okay. There is something nice about this module and I will tell you what. This module provides you serial data interface. It has an onboard RP-SMA connector okay, reverse polarity SMA female. It is operating the 2.4 gigahertz radio.

Its interference immunity is, interference is mostly restricted to direct spread spectrum technique immunity. It has ADC pins, it has 4 ADC inputs, each is 10 bit, and it has 15 digital I/o ports. So if you have analog sensors, you can connect four of them. If you have digital sensors, you can use them. If you want to connect it to a microcontroller, you can use the UART or SPI or I2C communication.

Nothing more than that. Just this module alone is sufficient for you to just collect the sensor and be done. You can just deploy it and then it starts sending data. No computation, nothing. It just acquire and just communicate. Look at the problem of trying to do all your computation on a gateway or in the cloud and so on. Then this is the best way to put it like a end device for acquiring information.

Think about the blind example I gave you. The outdoor light sensor can perhaps be equipped with a simple communication device like this and a light sensing module okay which is basically a sensor. Now if you look at the cost is quite low.

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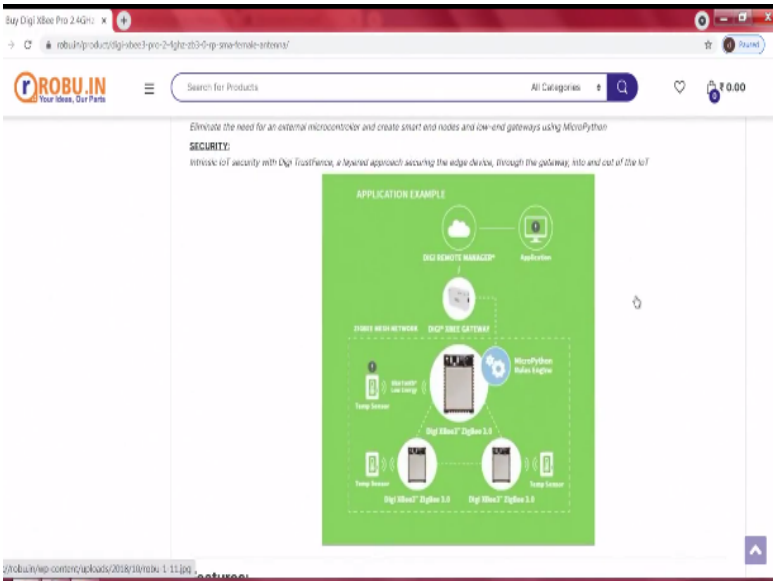

Good thing is about that example he gives here, okay. I like this example very much. What he shows here is you look at all these sensors. Look at what is actually happening. Here he has a temperature sensor out here.

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But this temperature sensor is communicating to a gateway. And he has at another temperature sensor, but this time it is communicating over the XBee 3, Digi XBee 3module, which is running another protocol which we mentioned just now is the ZigBee protocol. And this protocol translation between all these packets between Bluetooth and so on and so forth, how to interpret that packet, everything is known to this basic gateway system, basic device.

And essentially, this device in turn has the ability to communicate this via the Digi XBee gateway, which is essentially this device here and out onto the internet, right? So it can go back, can go out of the internet. So essentially, you can create a sort of a network, which will allow you to make a mesh out of these three nodes with you know including Bluetooth as a possible connection.

In other words, this gateway device has the ability to do even protocol translation. It can take Bluetooth, convert it to native some form. It can take ZigBee and then convert it into native form and so on. So the good thing about it is you do not have to worry about anything with respect to this, this part here because it allows you to just use this straightaway with analog sensor's interface directly.

So programmability, simplicity of creating IoT applications is extremely good with this ZigBee module. But you must know a little more than just you know looking at it from a module perspective, right?

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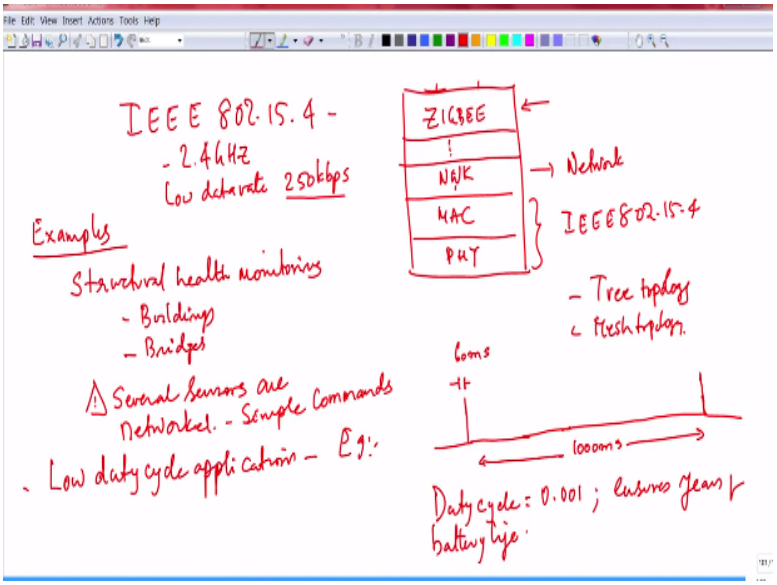

So let us look at formally what this module is all about and get into some details about this module. Well this module is nothing but defines the MAC and PHY which is defined by the IEEE. IEEE 802.15.4, okay. So this is the standard which is proposed by the IEEE and it is operating between the MAC and PHY layers.

Now this is the network layer and up here is the ZigBee application layer where applications can use this ZigBee stack which is developed by the consortium and start using these API calls for programming this module for either communication, for sensing and so on and so forth. Some of the examples of this technology where it can be applied is in structural health monitoring.

It could be buildings, it could be bridges and so on. You will have several of these sensors which are sort of placed there. And they can be connected in a mesh topology or they can also be like a tree topology they can be connected. And essentially keep on monitoring that bridge or that building in a periodical manner, okay. So it is just about send send send send send send kind of simple application that you may be envisaging.

Now these are essentially very low duty cycle applications, extremely low duty cycle. Let me give you an example. Here I have taken that ZigBee node remains on for a 60 millisecond period, acquired some data, does a transmission okay and again goes back to sleep for the remaining time which means every second it just is awake for 60 milliseconds and after which it goes back to sleep.

So you will really get good lifetime if you build systems like what I mentioned now, okay. So that is a good thing and where would you want to apply them? As I mentioned on several applications which require not only tree topology. So you can use it in tree topology or you can also use it in mesh topology, okay. So that is the good thing about the protocol itself.

Now one striking thing about this protocol is that it is low data rate. That is why you will get extremely good sensitivity because of the low data rate that it transmits. It can really survive under extremely high noisy conditions, okay, that is one thing. And inherently it has a modulation which is called, it is called a spread spectrum modulation. It uses direct spread spectrum modulation scheme, which essentially makes it extremely robust to any interference and noise.

And therefore extremely suited for this kind of large scale monitoring of environments that you have in mind. As I mentioned, data rate being low gives you the advantage of very good receiver sensitivity. And therefore you must know what kind of range this system actually can support. So we will have a look at that aspect as well.

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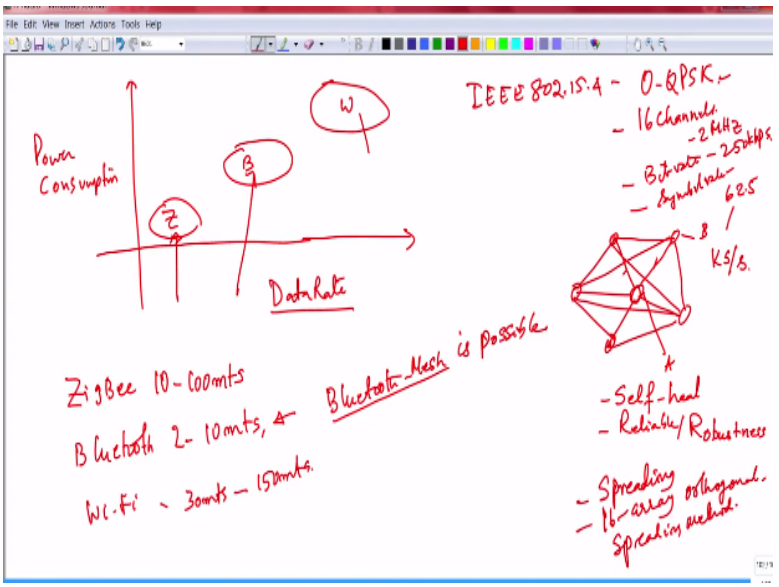

If you look at this picture, on the x axis I have drawn the data rate and on the y axis I have shown the power consumption. Z here stands for ZigBee, B stands for Bluetooth and W stands for Wi-Fi, okay. You can see that ZigBee is the lowest power consuming device and also the lowest data rate that you can get from it.

Whereas Bluetooth is slightly more power consuming and also data rates are not comparable in any way to the low end ZigBee system and Wi-Fi is again no comparison to what Bluetooth in fact offers. And therefore, it is also highly power consuming. So that is one way and you may also want to know the range, right? ZigBee the range can be, this can be anywhere between 10 to 100 meters, okay. This is ZigBee.

Whereas Bluetooth, Bluetooth can have somewhere close to 2 to 10 meters or maybe it maybe you can stretch it to 20 meters. Not more than that. If you take Wi-Fi, Wi-Fi is really long range, okay. It can connect anywhere minimum is 30 meters. And a maximum it can go is quite a bit in fact, alright. So it can go anywhere between 100 and even 150 meters. It is a quite a high data rate.

And also good range if you are looking at the different technologies. So you may want to pick that which you think is more suited for your application. Now earlier Bluetooth was one thing that people were hesitating to use, because it did not have

that inherent mesh capability. But right now Bluetooth has mesh. Bluetooth mesh is possible, okay? Mesh is possible.

Okay, and that is the reason why some of the times, if you had to decide between Bluetooth and ZigBee, people would go for ZigBee, because Bluetooth did not support the mesh capability. So mesh brings in a lot of features, right? It brings in reliability, resilience, because if there is a link failure on one of the links, let us say you take this case, this is connected here, here, here.

And let us say this is connected here, here, here and here. And let us say this is connected here, it is connected to this. And it is also connecting to this and it is also connecting to this guy, let us say. Now see the beauty of this system. They are all in close proximity. I mean, you can go on building the story here. For some reason from this node, let us call this A and let us call this B.

For example, if there is a packet going from A to B and this link broke, okay. You can do several nice things, is it not? You can give this packet to this node okay, and then get this node to, actually I have to draw this, get this node to communicate to B. So you take a detour, but it will start it can selfheal if there is a breakage, selfheal and highly reliable. It is also robust and so on.

So lot of nice things are possible with robustness because of its ability to withstand any sort of interference. The technique itself is very strong, direct spread spectrum technique. So it had its own advantages. But Bluetooth caught up also. Bluetooth also said we can do mesh and therefore now it is interesting to see what is it that Bluetooth I mean what is it that ZigBee can offer over and above what Bluetooth can offer.

But one thing is clear that its resilience is high, more suited for industrial environments and power consumption. That definitely ZigBee will far overtake the ability of Bluetooth links. So this is one aspect of what I wanted to say.

The second aspect is if you go into the details, a little more into details, you will realize that ZigBee or what I now would like to call as IEEE 802.15.4 in general uses a modulation scheme called O-QPSK okay. And it has a chip rate, it supports 16 channels. And channel bandwidth is 2 megahertz, 2 megahertz 16 of them, O-QPSK and bit rate, bit rate I mentioned to you is 250 kbps kilobits per second.

Symbol rate is 62.5, symbol rate 62.5 kilo symbols per second. Typically the symbol rate will be lower, right? This will be 62.5 K symbols per second, okay. I will just write it like that. And it has a beautiful 16 array orthogonal spreading method. So it has spreading orthogonal. No, I should write it correctly. 16 array orthogonal splitting method, okay. So these are some really good users I mean uses.

And because of the ability to give you very low data rate, it becomes a very attractive system. Now important things about this protocol is known to you. Let me draw another picture.

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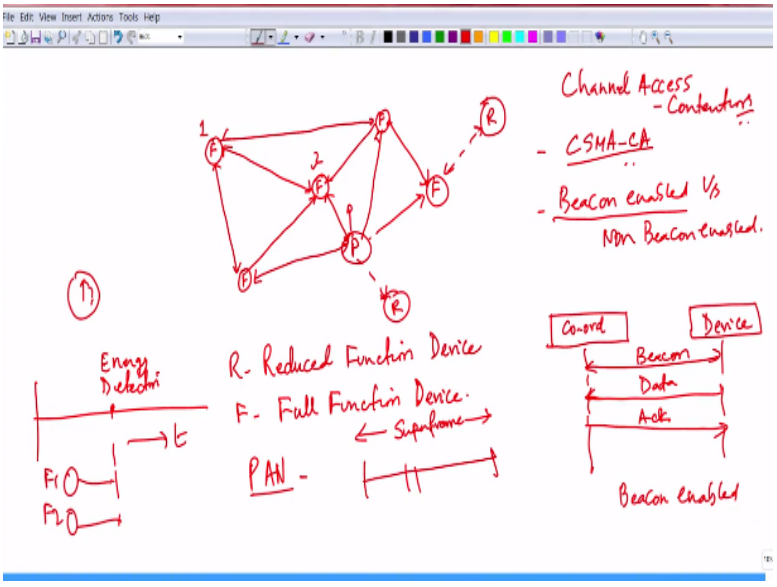

And what I have put here are F here, there are F's inside. There is a P here. Okay, so maybe this is not clear. So I will draw it big and I will put a P here. Okay, and I have put an R here. And again I have put a F here and so on. What this simply means in these in the ZigBee world or the 802.15.4 world is that this is a reduced function device. This R is a reduced function device and F is a full function device.

Folks, there is absolutely I mean I would say nothing to worry about these high sounding terms. There is only one difference perhaps between this R and F. If you look at F okay, take this case of F. This F has the capability to receive from another F or from another R and forward that data, okay. Whereas R do not does not have that ability to forward. That is only difference. It can only be like a edge node.

It may not have capabilities to forward. So go back to that XBee you know that little PCB I showed you on which there is a chip. Find out whether you can actually configure it like a F device or as a R device. Try to connect what you get in the market to what the protocol is saying. Only then you will be able to effectively use whatever is there in the market. Because these kinds of topologies are important.

What is P now? P is the PAN coordinator. It is called Personal Area Network coordinator, okay. It is like a gateway device okay, PAN coordinator. So that is what is P. Now if you look at what I have shown here, this is like a mesh topology right, this is a mesh, mesh topology. And you will have other types of topologies also like a tree.

You have let us say two nodes here communicating in turn communicating to another node and maybe it goes this way and it perhaps goes this way and so on, right. This is like a tree. Either you communicate like a tree or you communicate on a mesh. That will be something that you will have to determine based on your requirements. But the technology will allow you to do a meshing.

You have to program them accordingly such that you can put them into a mesh network, okay or you configure it into a mesh topology if you are looking for certain features, okay. So that is a very important aspect of the ZigBee, which you can configure. Now channel access essentially means that if you take timeline, if you take the timeline, and it is counting down, time is divided. This is time axis.

It is possible that F 1 and F 2 want to use the channel at the same time. F 1 and F 2, I think we should write it this way F 1 and F 2, both want to use the channel at the same

instant in time. Let us say it is here, this instant in time. Obviously that is going to collide right when you are transmitting at the same time. Therefore you need mechanisms to go over channel access requires contention and contention free methods.

Now the contention based access is essentially what we call carrier sense multiple access collision avoidance. And then you can also do non-contention based or you can also do a Beacon enabled method, right? You can also do Beacon enabled. We will talk about that as we go along. In CSMA the idea is that each node before it does a transmission looks for some energy.

It does what is known as an energy detection to see if the medium is free, okay. It uses its floor noise and checks whether the signal is above the floor noise and so on. If it is, then it knows that there is a detection, there is a transmission going on. Otherwise, it knows that it is free. But if it is free, it just does not jump in and send the data packet. It does some sort of random back off, and then goes back and checks whether that channel is free.

Even after a backoff, if it finds that the channel is free, then it does a transmission. This is typical of what carrier sense multiple access collision avoidance is all about. It tries to avoid collision and tries to sort of I mean ensure that it is graceful and tries maximum to ensure that there is only one node and that should be itself that should be utilizing the medium. So that philosophy is important.

Not always that may be useful. It may if you have an industrial environment where you definitely need access to the channel, then perhaps you cannot use this because you do not know this is probabilistic sense that you might also not get an access to the channel. Because if it comes if too many node is there, contentions will start increasing. And I as a node, I may not even have the smallest possible window to do a transmission.

So that is going to end up in a risky situation. So for that, the same standard 15.4 has defined what is known as Beacon enabled standard. So in Beacon enabled, what actually happens is the PAN coordinator, you know broadcasts a Beacon and divides the what is known as in Beacon enabled, you essentially have what is known as a super frame structure, okay.

In the superframe structure, nodes have first of all to begin with, they have to try and get hold of a slot. If they get hold of a slot, then they can use that slot repeatedly, whether they have data or not is not the point, they can repeatedly use that slot. So in a superframe structure, what actually happens is only first time, each one of these nodes have to contend and get a slot from the, it is like getting a pass.

You need a pass to go up, right. Supposing you have to pass to, permission to start moving up, or climbing a hill, it is like getting a permission. So you have to content somehow, you know first come first serve basis or whatever and obtain that pass. Once you have that pass with you, then that is it, you are given authority, a time slot over which you can keep transmitting.

So I think that is a fair enough thing. That is what actually happens in Beacon enabled transmission. It is not that in the Beacon enabled that people cannot content. People can content there also but there is also a non-contention part in the Beacon enabled superframe. So if you open up the superframe, you will see contention free and contention based. Both of them are there within the same slot.

I would like and encourage you to look up that superframe structure of ZigBee you know 15.4 so that you understand it much better. Okay, now in Beacon enabled, you see what all nice things can happen. You send out a Beacon and once the Beacon is sent out the device can give the data back because its time slot is reserved. And once the data comes you can get back and ACK, okay.

This is something that you actually supports between the coordinator and the device. Now that need not necessarily be the case in the non Beacon enabled case where you

would not have this, okay. Data transfer can need not be, if you take non Beacon enabled, you have data, in fact it will be just this, right?

In the non Beacon enabled, you will have device sending data to the coordinator and you might get an acknowledgment back in this direction. If it is successful, you will get an acknowledgement. If it is not you know that your data collided with someone else. So the notion of acknowledgment has now changed where you have to get an ACK for the data that you took a chance and you transmitted.

So this is for non Beacon enabled, this picture, non Beacon enabled. And for the beacon enabled, what would you do? In Beacon enabled, I will pull this out. But I will also do some nice things here. What I will do is I will send out a Beacon. Who sends out, the coordinator sends out a Beacon. This guy sends out its data, but not in this direction. It will be only in this direction.

And for which the coordinator may give a acknowledgment. So you will have three arrows in either direction, in the Beacon enabled mode. So all these things can be examined very carefully from the standard and the standard will essentially tell you something nice about how you can use this protocol in a very effective manner. All right. So let us move on.

There are other nice things about this protocol which you may want to use that is related to addressing, okay.

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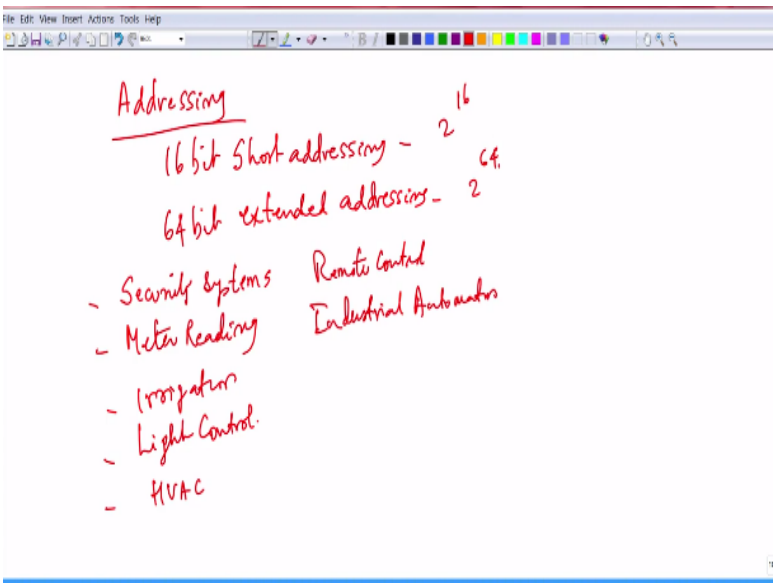

Very important concepts. In addressing it uses two methods. One is called 16 bit short addressing and the other is called 64 bit extended addressing, okay. Both are possible. Simply it means that if you have a smaller network, do not go in for 64 bit extended networking. Because with 16 bit already, you will have 2 power 16 possible addresses for nodes which is already a larger number.

And if you use 64 bit you will have 2 power 64 addresses that means 2 power 64 number of nodes can be there in the network, which in my opinion is very high. So try to see if you can manage with that just the 16 bit shot addressing which is good enough and that will also make the size of the packet smaller and so on. So this is an important part in the 15.4 stack.

Coming to applications as I mentioned, there are many applications for ZigBee. One can talk about security systems as examples. Then we can be talking about meter reading, okay. Then we can talk of irrigation, then we can talk of light control. Remember the example of blinds I gave you. This is something that you can definitely apply, ZigBee.

Well there are other technologies. You can also apply this HVAC, heating ventilation and AC multi zone systems. Then you can be talking about remote control, okay. We

can talk about industrial control, or industrial automation and so many applications out there, livestock and so on and so forth. Thank you very much.