D,esign for Internet of Things

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Lecture - 10
RFID Theory - 01

Welcome back, recall we did something on RFID with respect to 15693 that ISO standard 15693 and we showed a demonstration with respect to a medical application and so on. That the story does not end there because the range there is very limited, and you need to look at industrial environments where you need larger range, and you need standard protocols which essentially will allow you to scale up in terms of big warehouses and lots of tags that need to be inventoried and so on.

That obviously, you cannot do with the kind of medical application that we looked at, we looked at the Libre sensor and all that. So, let us understand the industry standard for warehouse applications or any pharmaceutical applications and so on, what kind of tags any factory environment you can think of usually uses the tags in the UHF range, the ultra high frequency range.

In India the standard is between 865 and 867 megahertz. So, this two-megahertz region is band is actually reserved for RFID applications.

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Remember, I mentioned this right in the first class, I even showed you this. You can see that there is a reader here and there is a phone connected to this and this reader is a UHF reader which is capable of reading different types of tags. This is frog 3D, this is dog bone, this is a dog bone tag, this is a short dipole tag, you can see continuously it is reading tags. Now we did this already.

I showed you a demonstration close up of all that. The point I was trying to get at is that while these tags exist each tag, why are they the three different types of tags. Obviously, the tags are to be manufactured differently, shapes have to be different, sizes have to be different, packaged differently. To take care of several situations and scenarios. There are also aviation tags. So, if you are to put it in an airplane and you want to qualify for an airplane environment, then you may want to look at aviation tags.

And airplane particularly has hundreds and hundreds of RFID tags for not just the cabin environment where safety vests are just below your seat, you have a safety vest. Each safety vest has a tag, RFID tag and if you are talking a twin iron aircraft, which is typical of let us say 787 and so on. There can be as close to 350 to 400 passengers and if you take airbus kind of airplanes, the A380 and so on you will have many more passengers.

So, hundreds of them hundreds of passengers. So, let us say you want to inventory those tags, because when you talk about items which are tagged you can be talking about doors which require maintenance, items which require maintenance and those which have to be thrown away. So, for example, if you take a safety vest, the safety vest has to be ensured that it is you wear it and it is to be used in an emergency situation particularly when the plane is flying over water.

For some reason it has to do a landing on water, it has to let us say come out onto the water, you have seen some videos I am sure were real situations, where the plane had to come on to the water, passengers had to come out that wear safety vests and then all that. That safety vest cannot be punctured anywhere it has to work, and it has to work and it is the material cannot be damaged.

So, damage can happen over the passage of time. So, you need to replace such tags. Such safety vest which means you need to know in one go, what are those tags that need to be replaced? And what are those tags which are present, and how many of them are actually there or if they are stolen, and so on and so forth. So, a lot of things you want to do with RFID. Similarly, you may want to look at a pharmaceutical or a warehouse situation, where you are interested in monitoring the movement of cargo from one carton to another carton and so on, many cartons.

In that carton, think of the today’s cold storage kind of a warehouse scenario. You have vaccines on one side and you have other let us say food preserver, food kind of environments on the other side. Both these situations you want to know let us say pre-empt and say I am interested only in the vaccine set of tags to be inventoried and I need them to be transmitted and transported out first. You go to the way a cold storage warehouse you find so many of them.

So, many cartons you do not know which one is corresponding to vaccine and which one actually corresponds to the perishable food typically, I you know, fish and mutton and all that vegetarian items plus vegetable any perishable fruits. For that matter all these are put into cold storage which is a big thing. So, cold storage kind of warehouses. So, there again, you need RFID systems to tell you when you want to filter out from a large set of them.

You are interested in selecting a particular subset of tartans for inventing them to see their date, to see their time, to see when it was packaged, when did it arrive, when did it leave, so on and so forth. All the tracking related thing monitoring, tracking all of that would require the essentially the use of large rooms. So, this is your 15693 will not work in that advance so, therefore, you need to UHF.

While on the one side, I showed you a reader of this size what is it that actually works in a warehouse environment, this reader will not give you more than one meter. I just used it because I wanted to show you an example. This is not the kind of reader that you will actually deploy, to tell you what exactly we use in practical situations. Let me show you this reader if the camera can swing to this direction, we can actually you see now this is the reader.

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This is the reader this is typical of the same RFID reader which I showed you, you can see that I mounted it on a robotic platform. So, you can see that, this is a turtle bot platform actually. And this robotic platform you can see here it is called Kubuki, this Kubuki platform is the one on which I mounted this reader, and I would arrest it and then try to scan all through the warehouse, take it inside on a standard path and actually select different cartons which are there.

And then inventory them to find out several information which is stored on the cartons, you will be storing information on the carton. So, please note both in terms of the technology both are the same, this is also UHF. This one is a mobile phone which I connected this is also a UHF tag, and this is from a company called it is from think magic, this is called think magic Astra. There are different companies which make them and usually there are multiple ports. So, folks this is the point so let us go back.

You know that there are both types of systems which are there, and one is for the warehouse kind of applications, and one is for you know small simple lab experiment that you want to do or you have one meter range and you want to quickly try, you want to be in UHF range. Look at this tag. Now we let us put back our focus on this tag, there is a chip here. And as electronic engineers, we should know in this course, what is this chip, there is no battery.

It is just an inlay; this is another type there is a dot here. You can study them in the thing that I showed you earlier. You should know what is inside the chip. So, let us focus and see what exactly goes behind. For that I will show you a picture. Let us shift to paper here.

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You see this is fully integrated passive UHF RFID transponder IC with 16.7 micro watt minimum RF input power. This is an IEEE paper. We are not interested in this paper at all. What we are interested in is this picture? Let me zoom it. Let me zoom it to show, you look here what actually happens.

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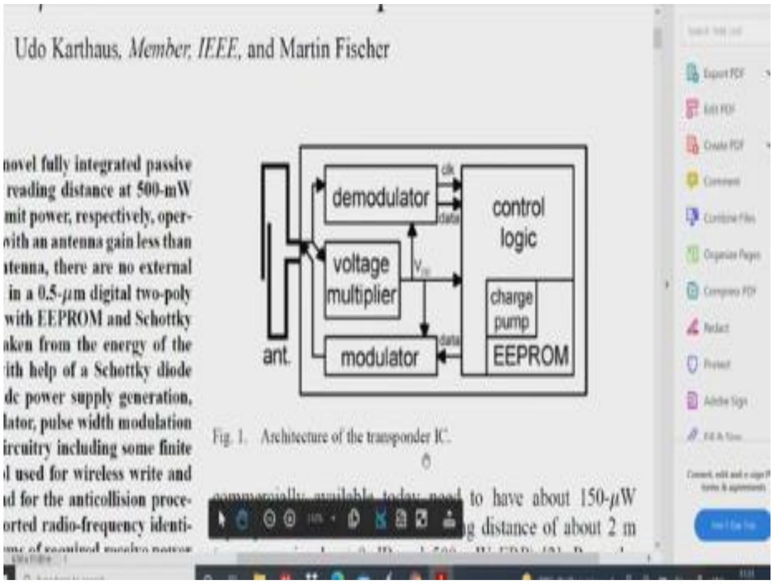

The reason why this RFID inlay actually works so well. You have an antenna, which we have seen here. You see in this one. You see this. This is the same antenna that we have here. This whole thing is an antenna the chip is in the middle here, the antenna is here. Similarly, the antenna is here, this is frog 3D it is oriented differently, and this is a dog bone and I said this is short dipole this is a short dipole kind of system. This is the same as what you see here, same antenna that you see here.

What you have is the RF energy is harvested, you are removing the carrier from that, and then pulling out the data that is available clock and the data is available to you, you have other circuits where you need to power condition the system, the voltage that is available is so small that several silicon logics, may not actually work. Therefore, you have to take that small voltage and multiply it into many stages.

Voltage multipliers are very standard circuits. So, do not worry about that part. And then there is memory is here, there is a memory system, there is a control logic here. Interestingly there is no controller, control logic is there. So, that means it has a state machine that state machine is fully integrated here. And depending on the command that comes in from here this control logic will do a few things.

That is about it, it will take the continuous wave, and then it will do a few things. This is the key reason why I wanted to show you this particular picture. If you are interested, you can go and read this paper, but that is of no interest to us. So, this black dot that you see on the RFID tag, essentially has this kind of circuit that has a simple demodulator. It then gives the clock and the data given from the RFID reader is fed to the control logic.

Based on the clock and the control the data that is available this control logic will traverse the state machine. Then it will put the data back. If the reader has asked for some EPC Gen two code, let us say we will come to that it has asked for a code then this control logic, the data will come here. It gets modulated on the control wave, on the continuous wave and then pushed out on this antenna back.

We mentioned earlier that there is already this backscatter communication which actually happens. And therefore, RFID continues to have that strong feature of backscatter communication essentially. So, you can see no processor, just a control logic as simple state machine which is implemented here. Well, it is simple, but then it does several interesting things. So, that is about why I wanted to show you here or I show you this.

Now, the next question that will come up to you will is what is this you had UHF standard that I am referring to? The standard I am referring to is this will give you everything here. This is the RFID air interface specification. This is about the RFID identity protocols, class one generation two UHF RFID protocol for Communications at 860 to 960 megahertz. This is some version fantastic document, the most authentic document you can ever think of.

You can download this document and understand this extremely well. Let me do a study of the contents. So, that you will get a feel already for what this document actually has. If you look at the first part conformance, there is some information related to the RFID systems, RFID itself. And then we will skip that. Because you will be able to understand it better. The protocol requirements particularly with respect to reader, configuring parameters to the tag are part of this.

And what the tag is expected to give back in terms of the way the data has to be read back by the reader is also mentioned in the protocol requirements. There is something called reader to tag and tag to reader. The reader to tag is called R in the right arrow going to tag T communication called interrogator to tag or R to T communication. Similarly, there will be T to R that is tag to interrogator communication. You can see here.

In this part you have a tag to reader communication, then FM 0 and Miller modulated subcarrier are encoding schemes from the tag to the reader. As far as reader two tag is concerned, it is usually pi encoding, pulse interval encoding it is called pi encoding. And from tag to reader is FM-0 or Miller modulated subcarrier encoding. Then tag selection. How do you select from a larger you know, collection of tags? How do you do tags selection? How do you inventory tags?

That means how do you read the tags? How do you access the memory of the tag? What specific information you are looking for is all discussed in this section on 6.3.2. Then you have the state machine which I mentioned talking about several states. You have ready state, arbitrary state, reply state, acknowledged state, open state, secured state, skilled state, and all that. So, all these states are clearly defined.

And the tag knows in which state it is at a given point in time. The tag also has a pseudo random number generator, I will explain why that is required. When you have large number of tags and reader throws power on the tags and it has no clue on the number of tags that population of tags, each tag actually tries to generate two numbers. One number is called a temporary ID which is called the random number and then it also has something called a slot counter.

I will explain that slot counter as we go along. And that slot counter is let us say if you take a four-bit value, that four-bit value can be anywhere from. Supposing you take a four-bit sequence you can have anywhere from all zeros to all ones that is 4 zeros to all 4 ones.
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So, what actually it does is the tag takes a number. So, what is known as Q value is given by the reader, the reader says my Q is 4. He will say Q is four or you can say Q is 8. It can say I should show like this Q is 8. Q number I will supply, reader says I will give you Q you find out take a random number from anywhere between, let us say if you take as a practical example, you take Q, I will give you as 4.

You can toss and get any number from all zeros to all ones randomly you must have. So, I showed you that there is a random number generator which is part of the tag, very important. In that control state part, there is actually a random number generator which is inbuilt into the tag. So, that guy picks some number it can be let us say 001 or 0100.

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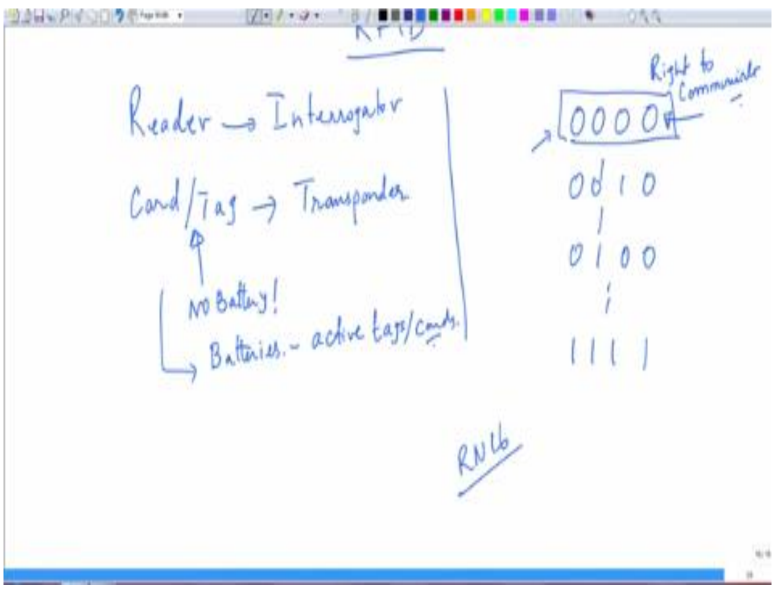

It can be anything and we can write that. It can pick any number from let us say all zeros, 4 zeros up to 1111. So, let us say one of the tags picks 0010, another tag picks 0100 and so on. It can go on like this. Any number it can pick, but that tag which picks this as the right to communicate, this is the important point. Please note, this is the right to communicate because it got all it somehow generated all zeros. So, it was able to communicate.

When the RFID reader through power on it, did two things, very important. You will get confused very soon. So, I am repeatedly telling you that there are two things it does. It throws a coin twice; think of it throws the coin twice. First time it throws, it generates a random number called RN-16, generates an RN-16, 16-bit random number generates. It tosses again, very importantly, tosses again and that time it will generate a random number between all ones and all zeros. Why twice you may ask. You now know. Reader has no clue about the ID of the tag.

It needs the ID because the ID if it knows and other information which is stored, memory part of the information. Then it knows this ID has this set of parameters. Do not hand way, this ID 96-bit ID is the ID of the tag in this 96-bit ID of the tag. For this 96-bit of the tag, the safety vest has to be replaced in 30 days, it is written there. In another ID, if you read another safety vest, it will say this safety vest was replaced, let us say last month.

So, it has to be replaced 6 months down the line or one year down the line. That information is there inside the tag memory. If you know the ID, and what is information that is contained there, then you have full information about when to replace the RFID tags. So, this is important too. But to begin with I do not know the 96-bit ID. So, I must tell the reader, please take me with my 16-bit RN-16 take me as the temporary ID.

I will tell you my real ID later. But take me as a temporary ID and you are taking me as a temporary ID because I won the medium. Why I won the medium because I got the right to communicate, because I became all zeros. So, two random numbers are generated. One is the purpose of assigning myself a temporary ID. And the second random number is for the purpose of two when the medium to communicate. Think about the following folks.

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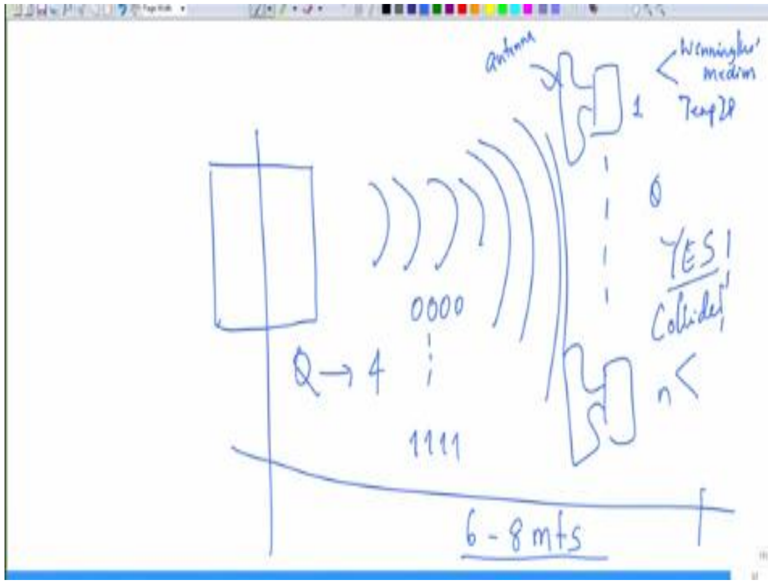

You have a reader, and you have reader throwing out energy. There are many tags here. So, we will now show a tag like this. I am sure you understand what this mean, this is antenna. And there are many tags is 1 upto n. Now I am sure you have a quick question. When the energy is thrown out both of them all this energy reaches all the tags in this vicinity. By the way, in UHF this can be up to anywhere between 6 to 8 meters.

Think about a warehouse, you cannot do the warehouse application with this little thing. I showed you this little thing it is not going to work with this. Because in one go, you are interested in a large area. So, you need a UHF reader, and you need a large reader like the one I showed you last time. So, I am connecting back here. Clearly two numbers are generate random numbers are generated by each one.

One is for the purpose of winning the medium and the other is for temporary ID. And like that each one of these tags will generate two numbers. One is for winning the medium and the other is for the temporary ID which it will associate. Now, here is an interesting thing. Why? Now what will happen? Let us say if I if the reader gave a Q value of four then the ability for the tags is to read anywhere to toss a coin and get anywhere from all zeros to all ones.

Your first doubt is why cannot two tags get the same zeros? The answer is yes, sure, why not? They will collide. This is a problem. So, you cannot do anything, you must the RFID protocol must take care of ensuring that it goes over collisions.

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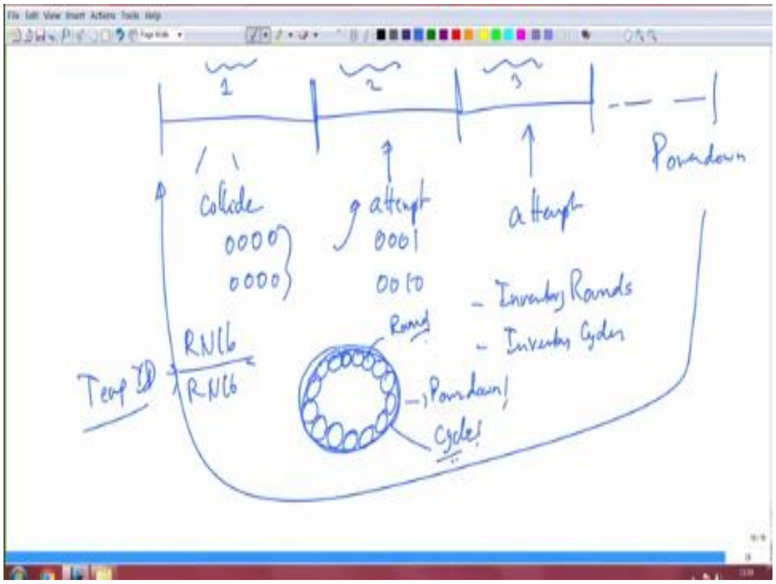

How do they do that? They divide time into slots, equal slots. And then if two tags collide here that attempt again here and attempt again here. Here they have collided because they chose the same winning the medium number. But they chose perhaps different RN-16 numbers. It does not matter. Random number 16-bit random number temporary ID I will call this temporary ID, temp ID. They chose different temp IDs, are they may want to same ID, does not matter.

So, the point is they collided I should put one more 0 here. The next time when they come back here the reader said hey man, you guys collided. So, now you have to attempt again. This time they had to toss the coin again. And hopefully the ones that collided generated like this. But they did not win the medium, that is okay. That is at least they were they did not collide. Somebody here maybe decremented to all zeros and had all zeros in this slot and then those that person could actually be communicating, he would have been the one the medium.

So, it goes on. So, you are to note that winning the medium is means that you should have all zeros that is the key takeaway from all this. So, then this is how communication actually happens, it will start with inventory, you have inventory rounds, and you have inventory cycles.

That is between inventory round, this is round 1, this is like inventory round. This is round 1, this is round 2, this is round 3, and all that.

Once you finish a certain set of inventory rounds, you power down and start a fresh inventory round then you will come back to inventory round one. So, you will basically do many inventory rounds, reader says I will do many inventory rounds, I will power down then I will start all over. And when I start all over, I start a new inventory round. In the second cycle, faster cycle is over. So, one more cycle and one more cycle. Each cycle will have multiple inventory rounds.

Think about a picture like this, this is an inventory round, sorry, inventory cycle. And this is an inventory round. I will just you can fill up. Then once it is done here, you power down. You power down and start all over. So, each one this can be think about this as an inventor round. This whole thing can be thought about as an inventory cycle. That is the key point. Look at these commands for instance.

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The query command for instance, you can see that there is a query command, there is a select command. See the before this query there is a select command. Select is a powerful command by the way. Select is saying supposing you take the case of cold storage. Let us say the cold storage warehouse, you have the cartons, hundreds of cartons of vaccine and you have hundreds and hundreds of cartons of other items. You are now interested in selecting only those which belong to the vaccine.

Because they have to be shipped out first from the or pull out those from the cold storage to be shipped out. Now you may ask another question, how do I know? I know that there are let us say 15 boxes of vaccine or 20 boxes of vaccine or 100. But whatever number you might know, because as you read from the RFID reader, you will know the number of boxes which are there having that particular vaccine cartons. But you do not know where they are.

Therefore, the problem of RFID is the following that you can only get the ID but you cannot get the location in a large warehouse. So, that is another problem. That limitation of RFID is only reading but not location. But so the lot of research that has gone to identify the location of a carton inside a warehouse. So, we will come to that separately just keeping you informed that it is the first step we need to understand whether a way to identify whether that where those cartons are.

Think about a pharmaceutical shop. Suppose you go and ask for let us say, some item, let us say Paracetamol, crocin which we know very well. Pharmacists may actually search, search and find that he does not find the Paracetamol anymore in is very unlikely because even in a remote shop, you will definitely find Paracetamol. In fact, many of our homes will have Paracetamol for sure. Anyway, just as a hypothetical example.

Now one good thing he can do is he does not find Paracetamol. He will take the reader and then he will just scan all in his shop all over in his shop, just to see whether he gets a reading of Paracetamol at all. Then he realizes that carton does not exist which means he is exhausted that it is not there. No stock there, right? So, stock checking is very simple with RFID, you can do it in seconds. So, think about things like that with select command.

Select, I can give a certain type of item that I am looking for then I can query. So, the query is another command, remember the RFID tag has a simple state machine only, nothing more than that. So, you have a query command, your query adjust. Query command essentially is a nice command, let me put back this picture here. Query is essentially starting off, let us say an inventory round, you have an inventory round.

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You start with the first inventory round, query comes here. When the query comes here, but tags get powered. Let us get into that detail a bit later. Then the tags generate I mentioned to you about RN-16, what two random numbers one and then the second random number as supplied by the reader. The reader is supplying the Q value, very important. Q value can be let us say something like 4 he may give, then he may even make it the 8 and he may make it so on and so forth.

Now, a Q value of four is the simplest thing to understand, let us say gives a Q value. So, the dumb tag says I got a Q value for from the reader. So, I must toss a coin between all zeros up to from all zeros to all once and I have to take a random number between that. So, all of that actually happens in the query command when the query command is issued, which I mentioned to you here.

Let us say, take the happy case, do not get into this complication take a very happy case. So, the happy case has no collisions. Let me get rid of this. So, let us say in the very first inventory round, I gave this one what is it? A tag uniquely got itself all zeros, and this tag here got 1 0001 and this tag got 2 and so on. Do not worry about that part. Just let us take an example. Now when you say query, this guy got 0, one tag got 0.

So, he earns the right to communicate. What he does is he sends out his RN-16 because he is 0, he sends out his RN- 16 and then waits for an acknowledgment from the either side. So, let us put that down. Let us go and put down that part.

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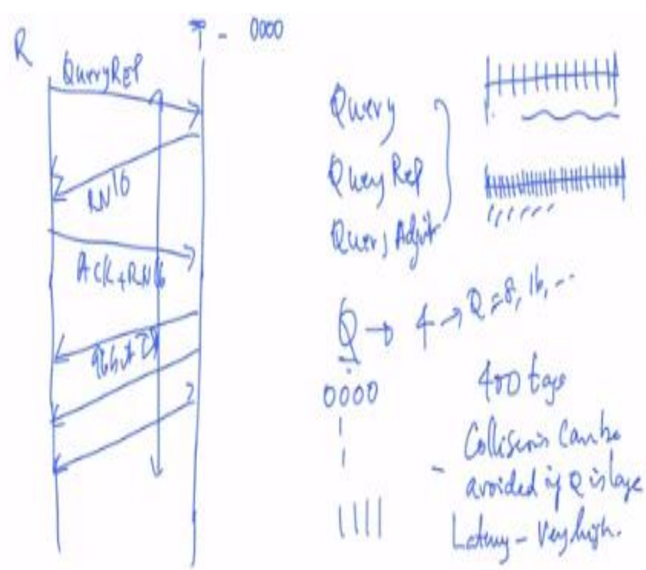

So, reader sends to tag: Reader sends, query. When a query is sent from the reader, tag communicates back, what does it communicate back? RN-16. When does the tag communicate RN-16? Only if its value is 0. Two random numbers, first random number is to win the medium, second random number is to generate a temporary ID which is RN-16. Now the reader says, great, I got your RN-16.

I am acknowledging your RN-16 back. So, RN-16 is given back here. When RN-16 comes back tag is happy, he knows that it has not collided. And then he supplies his 96-bit ID and then reader is not going to keep quiet. Reader says hey great, I got your actual ID I am going to ask you for more information about your memory. Now you supply me back whatever you have in terms of whatever you have in the memory location.

This memory location information will have to be supplied. It could be sometimes a block copy, or it could be a some type of different type of copies can happen. So, apart from 96-bit ID memory content sitting in the tag was also communicated back to the reader. Then here is the beauty. After all this is done here is the beauty. After all this is done, the reader may issue this command.

He may issue a query rep. You see here, you see a query rep here, he can give you a query rep. Now, what is query rep? Query rep is interesting. You had to go back for this. Query rep says the following. We took this inventory around, here we put all zeros. Here,we put 0001. For the second time, when you issue a query rep, this will count down by one. Now who has the right to communicate in round two?

This tag has the right to communicate in round two. This guy has finished, so he has to keep quiet. He is inventoried already. Therefore, he is going to keep quiet. And this tag is the one that will now communicate. So, you can see this is how tag 1, tag 2, tag n are all inventoried. The process of reading the tag successfully is the end of the particular reading of all the population of tags. The problem is not there. The problem is even more peculiar.

The problem is tags, once they inventoried themselves they have an ability to come back in one of the slots. They will actually come back. Although they are inventoried, they will not keep quiet. You have to tell them to just keep quiet because I have not completed all the n tags. Wait until I finish all the n tags. Otherwise, if you do not tell them, they will actually come back.

Think about you put something in a, let us say in a bucket and some insects or something, some insects inside a bucket.

And they are all trying to jump out of it. You take them out, you inventory them, put them back in the bucket. Again, they will try to jump out, but they will take some time to jump out. How much time do they take to jump out is a question? It gave us a naive example. But that is exactly what the tags do. They are not simple guys anymore, because the state machine says, the now I finished inventory, I need to get inventoried again.

One way of ensuring that they do not open their mouth again, actually none of the tags can open their mouth again, is to power down, then they have no energy at all. You can power down that is also applied in some methods. The readers will actually remove power. So, that they just get reset; they completely come out of that state. So, these situations also have to be taught off when we talk about it.

So, the query REP I mentioned to you is what here, if you go back here. You look at query rep and the second tag which counted down to zero, now starts communicating it is RN-16. And the procedure goes on it gives back an ACK plus the RN-16 echoes back the RN-16. Then the 96-bit ID is read then after the 96-bit ID is read, other related information depending on what the reader is asking for, either it could be an arrow like this, or they could simply be no arrow.

It could also mean that the tag may want to supply all what is there inside the memory of the tag. And therefore, the second tag is also inventory and this process can repeat for all the n tags. This is a very important thing. Now, what happens so let us see going back to this contents page. You have query adjust and query reply, the third one is query Rep. What is query Rep? Query Rep and query adjust, I am not going to tell you everything.

But I want you to read from this manual to understand it better. What is important is let us say the Q value that was supplied begin with was four. The number of tags are let us say 100 times this, that means there are let us say 400 tags. With the Q value of 4, you could only generate how many numbers? You could only generate 15 of them. All zeros to all ones, but you had so many more tags let us say. So, the Q value, the number of slots available.

The number of slots also will have to be increased so that you can accommodate many more tags. I just draw it with a scale just keeping this fixed, it is actually not true. This will also become a lot bigger, because there is a finite amount of time you need to complete this activity. In essence you have to increase this Q value you have to go to make it bigger, maybe you have to make it 8, maybe you have to make it 16 and so on.

And then inflate this such that you have enough number of slots for tags to count down and then get inventory automatically one after the other of course. Only one tag can be read at a given time right because that is what we said. Whoever wins the medium only one can be in the medium. And therefore, collisions can be avoided if you increase the Q value. Collisions can be avoided if Q is large but what is the problem if Q is large?

Suppose you have a small population of tags, very small fifteen times only you at 1 tag, 2 tag, 3 tag may be 10 tags or 15 tags and you put a large Q value. Then latency is becomes very high. So, what you have to do?

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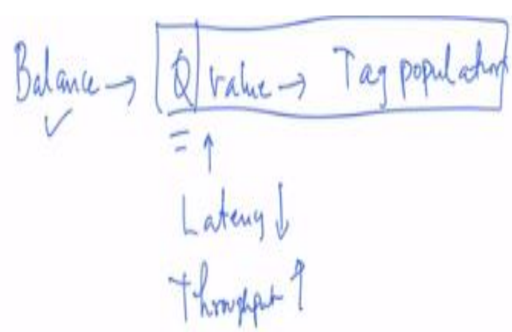


You must be able to balance between Q value and tag population. Somehow you should know for a certain tag population what should be the good Q value such that latency is minimized throughput of tags, read throughput is increased. There actually conflicting; goals, latency is low if throughput is either high happens in mostly natural way. But somehow you have do that and that is where the trick of IoT engineers actually come into big role.

And you know the scenarios then you can actually manage to put the right amount of Q value. The trouble often is you do not know the tag population. Reader has no clue of the tag population, that is the time when it has to happen in a hit and miss kind of thing. You try with one Q value; you get too many collisions then you realized there were too many tags. So, let me increase the Q value.

Then you may not get any response which means you made the Q value very high. So, again you have to come back and backtrack and say let me try a value between what I tried first and the second time and then try to get the tag read. So, it is a careful balance such that you will be able to manage the right Q value for a given tag population goes in that matter. Very good. So, that is exactly what I wanted to show you.

So, you can see that the full story can be built by just looking up that contents, table of contents and all these commands essentially are doing that, access command.
(Video Starts: 44:15)

Look at what all the reader is going to tell the control logic, which is state machine running on the tag, read, write, kill. Kill means what? You can kill the tag, you can write into the tag using RFID, you can read from the tag anyway. You can kill the tag that means it cannot respond again back. You can lock if you want to put something and lock it you can lock, you can do a block erase, you can do a block write, axis and so on.

So, all of that is essentially the part of this huge standard and I am sure you will greatly appreciate if you read this document. Now I will also tell you another important thing about RFID. The RFID systems, ITF is the most important thing. ITF means it is interrogator talks first. We set the other name for interrogator is the reader, the reader is also called interrogator. So, this is all mostly about ITS, the interrogator is talking first.

In India, the frequency range is 865 to 867 megahertz. Tags are different types; tags are also called labels for some reason. And information about the tag and its configuration parameters are all done when the reader talks to the tag on the RT calibration parameters RTcal parameters. Similarly, there is tag to reader calibration parameters called TR calibration parameters. The RTcal and the TRcal parameters are all specified when the reader starts talking to the tagging.

And how does it do? It begins with a tag that does not have a battery. It has to throw RF power the antenna has to harvest the RF power, power the internal circuitry. I showed you about that voltage multiplier inside and then the other control logic it has to derive the clock, it has the derive the data from it, demodulator block has to come, all that we have to be discussed, that is to power the chip.

Take the command from the reader and then execute the state machine and accordingly provide data back on the same reader. So, the back scatter communication actually happens. So, all of that means you have to configure these parameters and those parameters that are actually pushed by the reader. After powering the tag, it puts these parameters, and I will show you a picture. I am sure you will appreciate by looking at it. Again, coming back here, you can read this.

Now this continuous wave is a most important thing here, and I will show you a picture so that you actually understand how the tags actually get powered using this continuous wave. For that let me take you to another picture and that picture is here. This is the beauty. This is effect of generation 2 protocol parameters on RFID performers with a good paper and I will show you some pictures about RFID protocol.

Now if you concentrate on this picture, this is beautifully explained in this paper and it is very simple folks, very simple. It says the following. Look at how completely passive tag actually is able to talk to as the reader and the visa-verse. How the reader starts powers the tag and then makes a communication possible between the reader and the tag. What actually happens is the following. This is x axis is the time, y axis is the amplitude.

To begin with the reader will throw some RF power. CW1 is nothing but continuous wave energy that is thrown on the tag. What does the tag do? Tag takes the energy harvests it and then switches on its circuitry, nothing else. Just switch on the circuitry. So, the electronics is now on, the demodulator is on, the voltage multiplier has given the right voltage, the memory e square problem memory that can be energized now.

State machine is ready now. So, that part happens here then what happens is the data rate at which the reader is going to communicate to the tag is mentioned in terms of Tari, type A reference interval. It is telling the tag that I will give you a zero like this. If you know the zero like this, this is the pulse width then logic one can be 1.5 times 0 Tari or it can be two times Tari. So, you can have 1.5 times Tari or 2 times Tari.

Obviously, it simply means if you have 1.5 times Tari the data rate is higher whereas two Tari can be lower. It is very simple as you can see here it has implications on the data rate. But if you have one for a longer time, the probability that the tag will continue to powered is also be high. Because 1 means energy is available, 0 means no energy. So, this is a bad thing for the reader for the tag.

Because these instances the tag has been supported from its storage device like capacitors to actually execute the state machine. Whereas when this one is available it is all about good. In other words, CW is the one that actually powers the one is a good thing for the system. In this case, it is not to be called one it is just a continuous wave which is supply. Now data rate part is mentioned here as I mentioned to you.

The Tari is mentioned here to you. Now readers to tag parameters are usually given by RTcal. The RTcal gives the reader parameters and what parameters the reader is talking to the tag is given in this RTcal. The TRcal is what parameters the tag should use in order to communicate back to the reader is mentioned in TRcal. After this part is done now, the query, query adjust, query rep, select all these commands are sent here.

Now after you send the command, the reader sends the beauty. After it sends the command the reader says I have given you everything. I am going to give you a continuous wave now. That is CW2, you put back, back scatter the data on CW2 that is about it. This picture is just talking about just that part and you can see that several parameters are mentioned here you have unspecified to power up, CW2 is for the tag backscattering, commands are commands given by the reader then other parameters that we may want to consider is the back scatter link frequency.

These are simple equations you can see that the backscatter link frequency is dependent also on the TRcal. The tag to reader parameter and the divide ratio is something called a divide ratio, which is used and so on and so forth. These are the different types of tags which are there from different manufacturers. So, this was essentially to show you that a beautiful understanding of how the tag supplies CW1 to power the tag, mentions the data rate using this picture.

This Tari and zero and one. How zeros and ones and what rate zeros and ones are sent, then the reader to tag parameters, then the tag to reader parameters, then the command and then the continuous wave. You may now ask what are those important tag to reader, reader to tag and tag to read a parameters. We will discuss them as we go along.
(Video Ends: 53:27)

We should go assume more things about UHF EPC generation to RFID systems. We need a few things, but we need to do a little more. First thing that we may have to know is what are those parameters that the RTcal, reader to transponder calibration parameters? What are those parameters that are transmitted? Because remember there is only a state machine and they read at the tag side, there is no controller.

It has to match certain parameters as given supplied from the reader side. Similarly, what is it that is being expected from the tag on the reader side is also important. For example, the encoding scheme. What is the encoding scheme that I am expecting the tag to respond to me? Is it going to be FM-0 or Miller encoding? I must tell the tag, I as a reader I must tell the tag I want your data back in FM-0, I want your data back in Miller encoding.

Now you may ask why do you need two different types of encoding schemes at all. You could have done with a very simple thing. The problem is not so state forward. In outdoor, in environments where UHF tags are applied. Sometimes you may want to trade data rate, high data rate to that of better reading of the tags. Just by throwing RF power do not ever assume that the tag will get powered and then it will start responding.

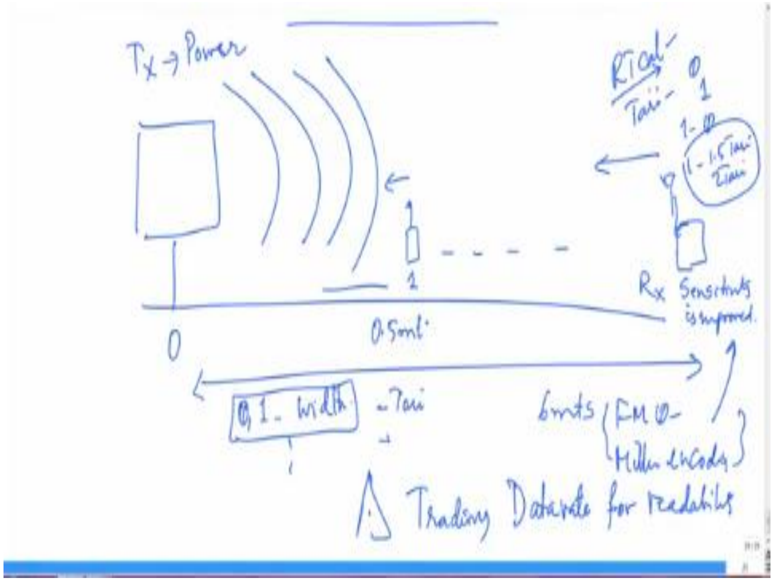
In fact, that is the last thing that will happen. You have seen that in the national highway authority of India NHAI, toll booths that sometimes the car has to move forward and backward before the tag is actually read because the orientation of the tag with respect to the reader has to be such that it does not get depolarized. So, if it gets depolarized it is nothing but which you can read actually can read the tag.

So, the tag antenna it is characteristics, the readers antenna it is characteristics all of it will determine on whether the tag will be read a successfully or not. A tag may be there just not read so these problems will exist. Therefore, people try to solve it in different ways actually people try to use multiple readers. And then they try to throw power from different angles onto the text whether the tag can be read.

So, on the one side you move away from bar code and manual methods, but on the other move towards technology related methods. But technology comes with its own baggage of problems which includes the problem of tag not being able to be read because of depolarization and so on. So, therefore you need certain critical parameters to be put on to the tag. So, that those parameters will assist it may not solve, but will assist, better reading of the tags.

And what do you trade? If you want to do that you trade the data rate. And you basically ensure that the tags get you know powered even with very low power they should be able to read. See, what I am trying to get it is think about the following situation.

(Refer Slide Time: 56:48)



Let say there is a reader here, at distance 0 and then it is throwing out power. Then there is a tag here, which is let say 1 meter away. No, I think I should not do that. I should put much shorter, 0.5 meters are here. And then there is a tag here which is if you take in terms of let me put it so that you do not have to do any trigonometry that you put it on the same. It is let us, say 6 meters away. Power is the same transmit power T x power is the same.

Obviously, this if you look at the way by which the power decays in a electromagnetic channel, it decays square of the distance that we know very well. Any electromagnetic signal Decays square of the distance. So, as the distance increases the receiver power here becomes extremely small. Therefore, how do you ensure? Where is this tag? you take this tag, this tag is very close, so it can respond better because it is received power is much higher as compared to this tag.

So, in order to trade the fact that you still want this tag to respond as well as this tag that responds you have to ensure that the tag has certain parameters assigned to it such that it is sensitivity is improved. You can do that actually. I mean the receiver sensitivity is improved. Therefore, there are some parameters of that nature and that is a puzzle you have to find out. What does FM-0 do? And what does Miller encoding do? Find out, find that out.

I cannot tell you everything, but I want you to read what does Miller encoding do in terms of particular aspect of you know, improving trading data rate, data rate trading, trading with what, better read range. I will say data rate readability, trading Data rate for readability. And simply write it like this, just figure out. Read, you can download and read and understand. This parameter will have to be mentioned by the reader to the tag, all of that is specified in the RTcal.

One of them one of the important parameters specified in the RTcal is the encoding scheme as expected by the reader when the tag communicates back. So, that is one of the parameters. The second thing is with respect to Tari, type A reference interval. Type A reference interval is Tari specifies the 0 and the 1. One Tari is that is specified for 0. I have logic one is typically 1.5 times Tari or two times Tari, I mentioned this already.

Whether it is going to use one time Tari or 1.5 times Tari or 2 times Tari it also should be known to the tag. So, therefore 0, 1 width I will call it. Nothing but width type A, here reference intervene is the width. How long does a 1 exist? How long does a 0 exist? That is what you’re specifying in the Tari. You are also specifying the encoding scheme as I mentioned to you that the reader expects from the tag and so on.

All of those parameters are nicely captured in this basic specification sheet which I showed you of the standard. So, let us turn our attention to that.

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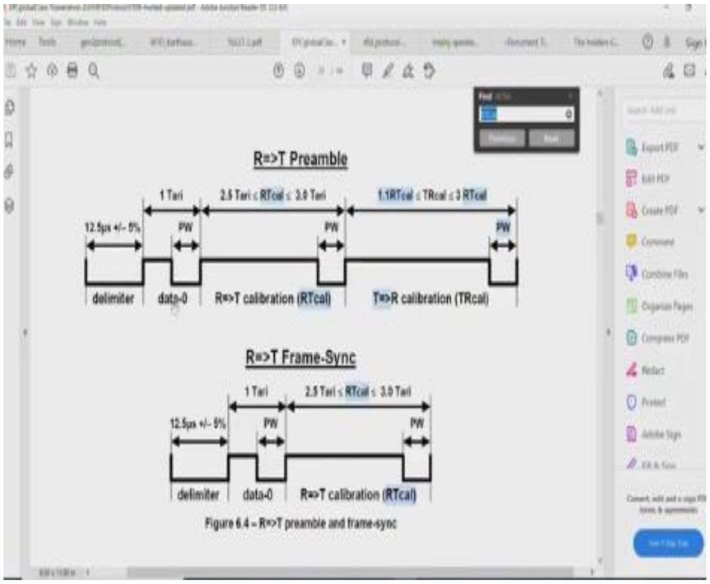
Look at what is written here. An interrogator shall begin all reader to tag signaling with either a preamble or if frame sink both of which are shown in figure 6.4.

(Refer Slide Time: 01:01:49)



What does it say just look at the picture, you know everything this is the delimiter, this is the data zero, this is one tari which is data zero. It actually tells you what RT calibration parameters. This is 0 and it also mentions about the fact that if this is 0 then you have RTcal, calibration parameters lying between some unit of this Tari. This is the RT call its lies between now between 2.5 and 3 Tari or the RT calibration parameters.

And the TRcal parameters are lying between 1.1 times RTcal and 3 times RTcal. So, those calibration parameters are available here that is what will be saying. And then the frame sync is also mentioned here. Again, you have the delimiter you essentially have the same thing which is the one Tari and then the RT call parameters are shown here. This is just showing you that the frame sync typically looks like this.

Synchronization between transmit and the receiver systems have to be synchronized and that is shown in this picture. Now we did not explain fully what are the parameters carried. That is shown here in great detail. The interrogator shall set RTcal equal to the length of data 0 plus the length of data 1 symbol. See the beauty. Now it knows, Tag actually knows what is the length of 1. Because it knows that one is definitely here.

How much of 1 is there is written here. So, it says you read it carefully, you know. You know data 0 and you also know 1 because, you know it indirectly. Because it is RTcal is equal to the length of the data 0 plus the length of data 1 symbol that is 0 and 1 both included how much it is mentioned here. From this you subtract data 0 you know, what is the length of data 1. That is all, very simple.

Read it crisply otherwise you may get confused and that is the reason I mean assisting you to read it carefully. A tag shall measure the length of the RTcal and compute pivot, pivot is exactly RTcal divided by 2 that is what is mentioned here. You can see that the tag shall subsequent interrogator symbol shorter than pivot to be data 0, anything less than the pivot is data 0. And subsequent interrogator symbols longer than pivot to be data 1, fine.

Because this comprises of 0 and 1, you are essentially subtracting as I said. So, in a way if you remove data 0 that means you to do, you remove data 0 from it, you know what exactly is data 1. And that removal process is nothing but the RTcal divided by 2 which is the pivot as simple as that mentioned here. The tag shall interpret symbols longer than 4 RTcal to be bad data that is also mentioned here.

Prior to changing RTcal, an interrogation transmits CW for a minimum of 8 RTcal. You need power in, you need power to you need to supply power to the tag to power up. How long should that power last? It should last for a minimum of 8 RTcal. If it lasts, then the tag gets powered. Now, let us look at the TRcal. TRcal is an interrogator shall specify a tag’s back scatter link frequency its FM-0 data rate, or the frequency of its Miller subcarrier.

Using the TRcal and divide ratio DR in the preamble and payload respectively of a query command that initiates an inventory round, beautiful. The query command is issued by the reader and that actually is quite loaded. An interrogator shall specify the tags backscatter link frequency using the TRcal and divide ratio in preamble and payload respectively of a query command that initiates an inventory round.

Kind of recall, query; when you issue a query command by the round; the inventory round starts. What is the data rate from the tag to the reader? That depends on the TRcal, who supplied the TRcal. Of course, TRcal is also supplied from the reader to the tag. So, TRcal here right here, you can see. The TRcal and divide ratio in the preamble and payload respectively, query command that initiates an inventory round.

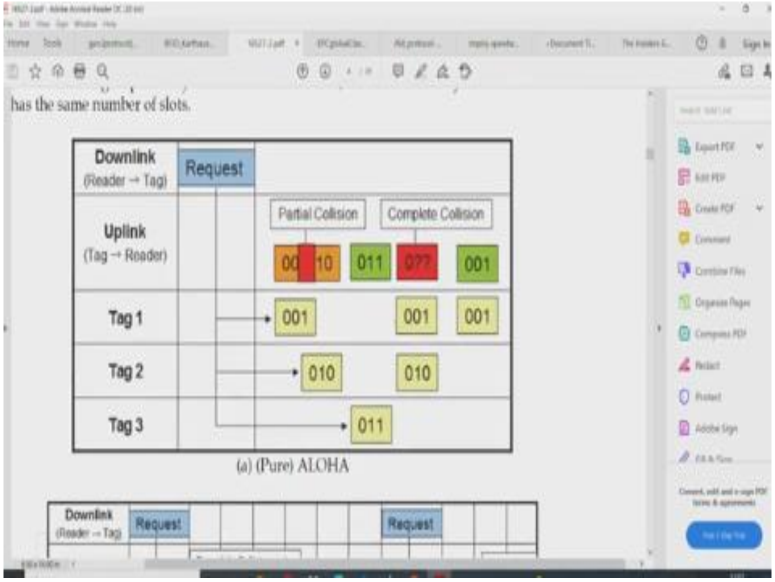
Equation one, this is DR, divided ratio divided by TRcal actually tells you the link frequency that is also mentioned here. So read it carefully folks, you will know several things about an RTcal parameters and a TRCal parameters, that are sent by the reader. The tag here is totally dumb, it knows nothing it is just running a state machine. Now it should also the reader should also say what frequency it is, what is the modulation scheme that it is using. Is not it?

That is also mentioned whether it is doing ASK or whether it is doing FSK and so on. So, this document tells you all about that so I would strongly encourage you to understand UHF gen 2 EPC, in great detail by reading this particular document. I have glossed over it, but I am sure you will understand if you read a little more in detail by spending some time, you will actually understand this in great detail.

There is one thing for sure which I want to covered and I want to spend another five minutes talking to you about that part. And that brings us to a very important point about what does the wave? How does the system come out of collisions and how does this complete process actually working? I wanted to show you a picture. For this I am referring to this document which I was able to download, you can also download these documents.

RFID model for simulating framed slotted ALOHA based anti-collision protocol for multi time identification. I found this document to be good and you can download this document. And I will show you what exactly is happening. The UHF Gen 2 EPC Gen 2 actually uses frame slotted ALOHA. Now why you have to use frame slotted ALOHA? Just look at an example which is shown here.

(Refer Slide Time: 01:09:43)



It is quite simple, first understand pure ALOHA then let us move to slotted ALOHA. In pure ALOHA, there are three tags, let us start like this. There is a request sent out by the reader to the tag. And there are three tags and now the tags have to respond back. When the tag responds back to the reader, it is called uplink. What actually happens? This is what is seen in the first row what you see here is what is seen at the reader.

This is what is happening at each one of these tags. The tag gives a number let us say 001 it is just an example, it is just not mimicking the exact protocol, it is just for understand. The 001 and when the random number expired, this is because tag 1 communicated first. Because it is random number expired first, it got. So, it started as we just said, let me transmit it because this is pure ALOHA. Just when that one was being transmitted the second guy started.

So, this 1 and 0 got collided. Here three was lucky, three did a communication in a random way such that it communicated. After these two communicated, 011 came in here successfully. Problem with this is it has partial collision. I am sure you have studied this in your undergrad, but this is just to recap. There is also possibility that you have full collision that is both the bits are actually they can have perfect alignments of the data transmissions and they can collide as well. This problem is now avoided in slotted ALOHA.

What you will avoid is not collisions, but what you will avoid is partial collision when the reader sends out a request. The difference between this picture and this picture is, look at the number of vertical lines. This hardly any vertical line here whereas if you look at this the full of vertical lines that means time is divided into slots. Tags cannot transmit just because they have data that wait for the start of a slot only then they can transmit.

On the same picture tag one, reader sent out a request. Tag one did not collide because it transmitted when other tags did not transmit. Whereas tag two and tag three transmitted to the same command, they collided then. Now look at this picture very carefully no where you will see partial collisions which we found here which means throughput improves data rating improves because, partial collisions are fantastically avoided.

Full collision, yes. No collision, yes. Partial collisions, no never a partial collision. Therefore, RFID system Particularly use partial collisions that is all I wanted to show you from this picture and this picture is written beautifully. I am sure you understand this completely. There is one more topic which I thought I will spend time on. And I wanted to show you this picture. This picture brings you to a very important thing of all what I said, and you will see the summary of it.

Look at what is actually happening. The reader sends out a power up the tag which is equal to 8 times the calibration parameter. I have already mentioned this. So, 8 times that calibration parameter it has transmitted and put the tag to energy. After that what happens? Tags send out query. Now the tag is powered the tag now responds with the RN-16. Because it counted to 0 luckily when the CW was available it put back that RN-16.

For that RN-16, it got back an ack from the reader. Once it got back an ack it transmitted its EPC Gen 2 information. Then the reader said great, I have invented you and let me inventory the next tag. For that it pushed out the query rep. This cycle goes on and on and on. This is a happy scenario. Let us look at what happens when they collide. Again, the same thing, query is sent CW is given back. So, that the tags can backscatter the data. Two tags Counted to zero.

At the same time the transmitted RN-16, they collided and now query rep issue here again. You can see now there is a slight difference. The reader has understood that there is a collision, it gave a query rep for some reason. Figure out that then supplied the CW. Nothing came here that means it must have changed in this query rep, you must have done something to change the Q parameter.

The Q value must have got edited, must have been new Q value may have got supply. So, nothing came and then again it issued a query rep and so on. So, you can have collisions, you can have no collisions based on the Q value that you supply. This picture essentially captures all of that in a nice manner. So, this is another thing I wanted to tell you about and this I took from this paper.

Multipacket reception, it is actually I am not interested in multi packet, what I am interested in is this picture. So, do not worry about so much about the title. See the point is what does the query command do is beautifully explained here, that is why I want to draw your attention. See here the query packet not only configures the uplink tag to reader such as encoding scheme, FM-0, Miller 4 and all that and frequency and amplitude shift in modulation.

But also announces the frame size k in what we were using is our notation called Q. This is nothing but the Q value. Now all of this essentially are carried in the query command itself. Select and then query all these things are essentially captured here and it talks about the inventory rounds and inventory cycle. This is about RFID in a nutshell, we need to spend another some more time trying to understand sessions and targets and also some aspects of multiple reader cases like there are two readers in a case.

We do this as we go along because they are very important for you to get an overview of RFID system. Thank you very much.
(Video Ends: 01:17:15)