Design for Internet of Things
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Lecture - 26
RFID protocol and applications

So let us understand RFID from a protocol perspective right. So, RFID protocol is important. You have to understand this protocol well.

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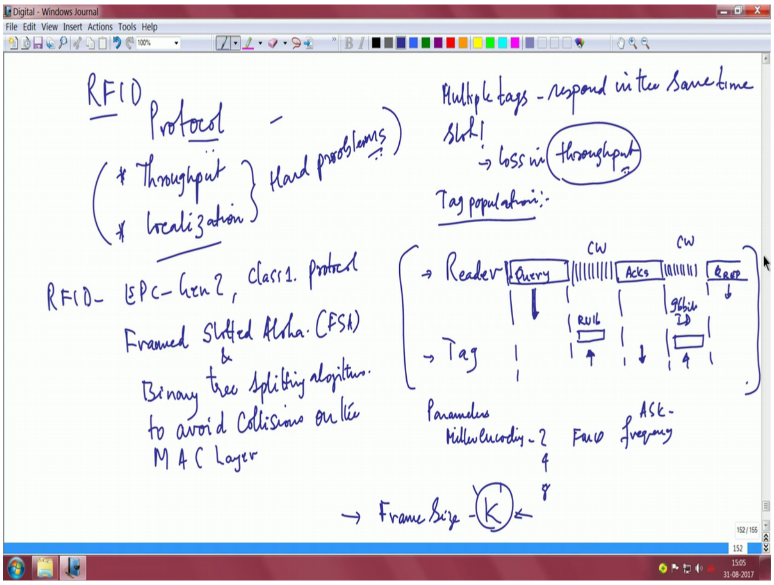

If you want to tune some of the parameters that we have discussed during the demonstration, sessions, targets, persistence time So many things we said right. So, so in a capsule let us quickly understand protocol and the hard problems that are currently prevalent in the RFID domain. One hard problem that occurs to me is related to throughput. The second hard problem is related to localization. I would say these are 2 hard problems. And let us spend some time understanding this RFID protocol, with view of trying to give you an idea of how to solve these 2 challenging problems or hard problems in the RFID domain. So, let us see how we can start with this throughput and move on from there. Firstly, the when we talk about RFID we are referring to EPC-Gen 2, EPC-Gen 2.

By and large class 1 kind of protocol class 1 protocol EPC-Gen 2 class 1 protocol. Essentially this protocol adapts what is known as a framed slotted aloha. It is also called

FSA it uses it adapts FSA and binary tree splitting algorithms; to do what? To avoid collisions on the medium access control layer: why does this happen? This happens when multiple tags multiple tags multiple tags respond in the same slot, that is the problem. So, what happens 2 tags with the responding the same time slot and saying slot I mean the time slot ok.

This is what will happen the data signals that arise at the reader is mixed mixture of both. The reader does not know how to decode and therefore, has to discard both the tags the data coming from this tag because it just cannot make out everything is garbled, right. Essentially this is loss in throughput right. So, that is what I was trying to say which means if you have a very large tag population, if you have a very large tag population and you are trying to meet certain performance objectives, of reading all tags within a given time that is assigned to you it is not going to, how well does the whole system cover all the tags being read is the question.

Because you can have tags colliding and not all tags being covered during the time when you are reading for a given time you know you are always specifying with respect to a given time why is that important. Because you go into a departmental store there are millions and millions of times which are tagged know maybe, maybe a million items which are tagged. And you are given let us say I give you half an hour and you have to just give an inventory of all the items which are tagged there, suppose in some kind of time limit is given to, you are expected to ensure that all tags are read and within the given time frame that is given to you. So, unless you have a very high performance algorithm you will end up with these slots tags colliding due to this and then you will have a loss in throughput.

So, we must understand how the protocol works, and what possibility exists for us to sort of have a handle on reducing the collisions and therefore, improving the throughput. So, let us put down a nice picture, which will tell us about how the system how throughput can be improved. So, there is essentially it is a challenge to improve the techniques there are quite a few techniques. So, let us see one-by-one. I will draw a picture and explain to you show you the way the protocol actually works. So, let me quickly summarize this protocol and I want you to look at this picture. Here is the readers view and here is the tags view. Now basically the reader sends out a query command to all the tags and the query command contains several parameters which essentially talks about the miller encoding parameter, whether it should do miller encoding 2 4 8 or whether it should do f m 0 encoding. And also the amplitude shift to the frequency when it does an amplitude shift king. The frequency that has to be required all these parameters are sent out in the query command.

Now, in response to that the tags are already powered now. And what the tags will do is and apart from this of course, as I mentioned to you the K is also sent, capital K essentially is the frame size essentially this will talk about a large number of slots which are available for the tag is actually knows the number of time slots which are available for sending out it is you know 96 bit ID. Now the 96 bit ID essentially before it actually can go out here the 96 bit ID can go out here, it has to first initially send out a 16 bit random number and this we will call as the RN16.

As you can see soon after the query the RN16 goes out, and if there are no collisions the reader accepts all these RN16 random numbers from these tags and it will respond with an ack in this direction in the downlink direction. In response to the ack the tags will actually send out their 96 bit ID because they know that they got a successful ack which means they are not collided, and then it goes back to the reader and the reader in turn will send back a response called the Q rep which is essentially the response. This in a sense is indeed the RFID protocol working between the RFID reader and the tag tags are all read, right.

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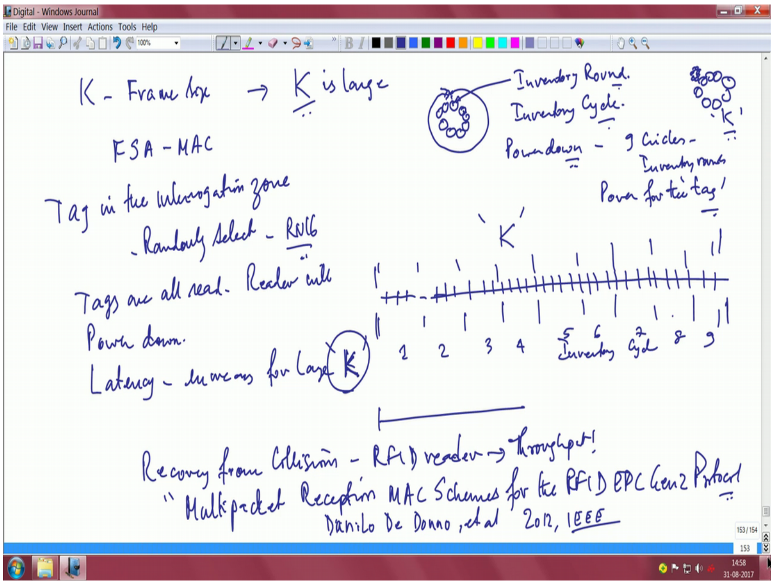

After all the tags are read, the reader will power down will power down. It is very easy to write this, but difficult to ensure that all tags are actually read right. So, that is what is important. We refer to an individual frame as an inventory round and a series of inventory rounds between power down periods as a inventory cycle. So, I will show you a picture, which will allow you to appreciate what I am saying. I will show you circles like this, I will draw circles like this, I will start from here move on and put it here exactly here ok.

Each one of this small circle which I have shown here is indeed called inventory round, essentially complete set of inventory rounds making up a circle this whole thing is nothing but the inventory cycle. So, once it comes to this arrow back here there is a power down. Now it is easy to see all through the circles 1 2 3 4 5 6 7 8 9 all through this 9 small circles that I have shown which we would now call inventory rounds, I mentioned to you already. There is power for the tag if there is power for the tag within an inventory cycle. If a tag was unsuccessful here send out it is RN16 and get an ack for it is RN16 I would say not unsuccessful in sending out an RN16, but not getting an acknowledgment back for it is sent out RN16, because of collision. It can attempt here or if it is unsuccessful here it can attempt here ok.

Therefore K spans the whole of this inventory cycle this capital K; that means, we will have number of slots, right; number of slots which cover the complete inventory cycle. So, 1 2 3 4 5 6 7 8 9 you can pull off this, right. Which essentially is one each individual cycle in each round inside. So, all along from here to here there is this is power down to power down this again will have a power down here. So, all through there is power. So, if I slot if I tag does not make it in one inventory round it can try again and again and again and again. Basically the dimension of the size of each of these circles can also be made very small, right. You can have very small circles and you can have very large circles. Essentially in a way you can imagine that K can be adjusted. The trouble is if you have a large K it is good for tags to they will keep finding an opportunity to communicate successfully to the base station, but the latency takes the beating, latency increases or large k.

So, therefore, you have to choose between a very large value of K and ensure that you still do a good coverage, right. Even to find out what is the correct value of K is not easy and therefore, lot of work has gone behind in several pieces in literature, where they choose the, right. Value of K such that collisions are close to 0 at the end I mean at the end of inventory cycle and all tag would have successfully and therefore, all tags would have got successfully registered there by there 96 bit ID. But the real challenge in this area of RFID is recovery from recovery from collisions where on the RFID reader.

And this essentially means that there this is a challenge to improve the throughput. I must point you to a nice paper which does talk about this challenge and the paper whose called I will just write the title, multi packet multi packet reception multi packet reception Mac schemes for the RFID EPC-Gen 2 protocol. The authors are Danilo De Donno and others. This was published in 2012 by the IEEE ok.

So, there this paper actually we will talk about how does one recover from collision, how to improve throughput? And basically it is a nice challenge and that is what I mentioned about the fact that throughput improving throughput becomes an important requirement for RFID systems. At least if the RFID reader is able to recover one of the 2 tags which are collided then it is already an improvement right. So, the reader had seen this paper or actually talking about how to recover from 2 nodes colliding may require at least one from that.

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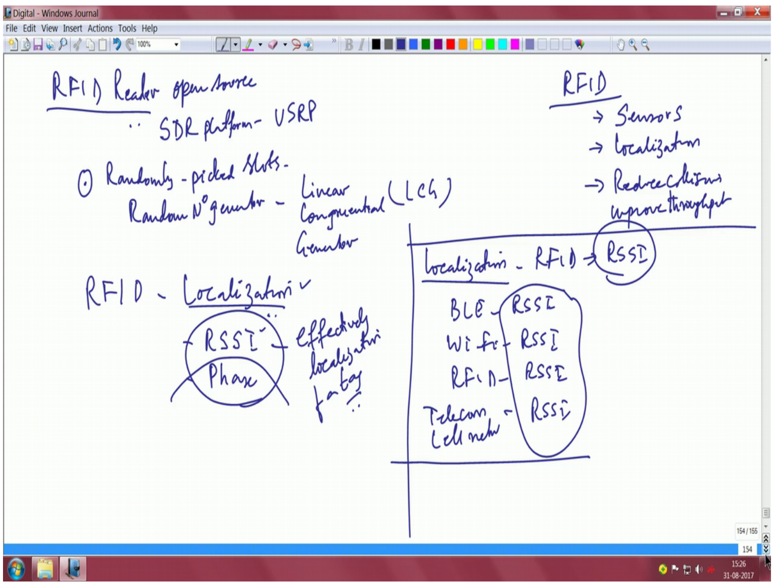

And then what they do is it is interesting if you are interested you should also try you can run the RFID reader software, apart from just buying commercial software we can also use RFID reader from open source, open source and run it on software defined radio platforms. There is a platform called the USRP, you can run it on USRP platforms that the since the tags are reading the slots are picking a slot randomly picked slots, right. Picked slots it is important for you to note that the random number generator if it is a good one can also reduce collisions in a way right. So, there are some very standard algorithms particularly there is a generator called linear congruential generator LCG, LCG is a very common sudo random number generator and this can be used ok.

So, this is an important thing and that is what basically the protocol is actually talking about. So, the second challenge I mentioned to you which is a heart problem in the area of RFID is related to the problem of localization. If you look carefully the demonstration that we did the other day the other time you will see that 2 parameters are available towards one is receive signal strength indicator RSSI and the other information that was available was related to phase.

These 2 parameters can be effectively used to perform localization of a tag. And many many papers have appeared in literature on how they can be used. It turns out that phased based approach is much superior compared to RSSI, but nevertheless RSSI also for very simple applications seem to be already good enough. For very rough location estimation. Why is this an important problem at all in RFID? First you have to understand, that if you take the use cases for RFID it is used in let us say warehouses for logistics and all that, take pharmaceutical industry you dump a number of let us say drugs in a warehouse. And you are interested in not identifying all the drugs which are there in, but you are interested in locating you are interested in locating a particular drug.

Now, that information is not going to be made available to you by just reading the tag ID, right. It will just say the tag is present and therefore, the dug is present where it is present in the warehouse is never going to be revealed to you, because there is no simple way. Therefore, how can we use RFID for localization? We already mentioned some nice things about RFID and it is power. Just to recap again RFID can be interface with sensors, RFID can be used for the purposes of localization. And RFID can be read in quick time and the challenge there is to reduce collisions reduce collisions and improve throughput.

So, that many many hundreds and thousands of tags can be read in quick time and there is so, these things are already there. So, let us understand this localization challenge of in

RFID, but we will restrict ourselves to just the RSSI base method. And this is just to give you an idea of on localization rather than not rather going to the details of localization algorithms. Just concentrate on RSSI part in general this RSSI is available on almost all types of radios ok.

BL, Bluetooth low energy can give you RSSI Wi-Fi can throw some information about RSSI. RFID again RSSI, cellular networks essentially the telecom networks they also give you telecom cell networks, they also give you RSSI. So, there is something about this receive signals strength which you can exploit. And try to see whether you can roughly do some sort of localization. I will also tell you that while it is possible what the limitations of RSSI are also with respect to going in for superior methods we choose phase as a possible signature for purposes of localization.

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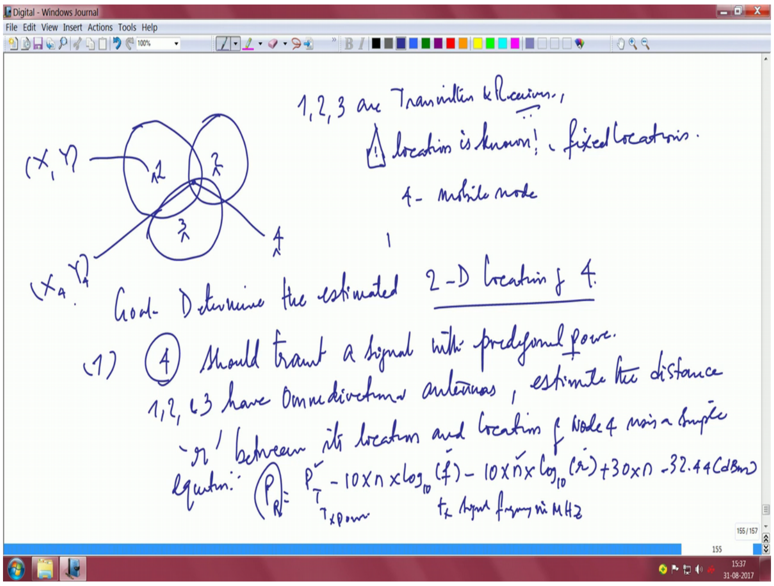

Let us start by taking a very simple picture. Essentially this and this dot here is also like this. 1 2 3 are transmitters assume that 1 2 3 are 1 2 3 are sort of let us say are transmitters, but whose are basically are transmitters and receivers from there basically transceivers, but importantly their location is known. That is important, locations of all the 3 are known; that means, they are in fixed locations they are in fixed locations alright.

The fourth node let us say this node number 4 is a mobile node is a mobile node. This is node number 4 which is essentially a 4 node. Now the 2 dimensional so, what you can do is, and the goal is what the goal is to determine goal is to determine the goal is to determine the estimated 2 dimensional location of node number 4. You are interested in 4 s location 2 dimensional location essentially we are talking about X and y, but well this can also be X hundred to 3D and we can also get z and all that, but do not worry about it. So, just look at the requirement of 2D location of 4. Now the location estimation basically begins with 4, location estimation the first step is what should 4 do? What 4 should do is it should transmit 4 should transmit, transmit a signal it should transmit a signal with pre defined power. Transmit power is known to 1 2 and 3 remember 1 2 3 are transmitters, but also receivers. They can also receive the signal from 4 that is very, very important.

Now, assuming that all these 1 2 and 3 have only directional antenna, they all have only directional antenna, fix to each one of them. You can easily estimate you can now estimate you can estimate the distance r between it is location it is location and location of node 4 with a very simple question. Everything comes from the link budget equation right So, P r received power is transmitted power minus 10 n of log n log 10 of f minus n log of this r plus 30 times n minus 32.44 in dBm, do not worry So much about this equation. It simply says the received power is nothing but the transmitted power P T this is transmitted power ok.

Again in dBm of node 4 that is that is what we said it should transmit with a predefined power that is the predefined power P t, P r is nothing but the received signal strength. P r is nothing but the received signal strength, RSS at the fixed node location, f is what the transmitted signal frequency f is the transmitted signal frequency in megahertz basically it is in megahertz it is in megahertz. N is what path loss exponent, this n is the path loss exponent each technology and each system will have these numbers and I will not go into the detail. Basically it is telling you about the distance square law, essentially builds on top of the distance square law. N is the path loss exponent and r is the distance in metres r is this distance in metres.

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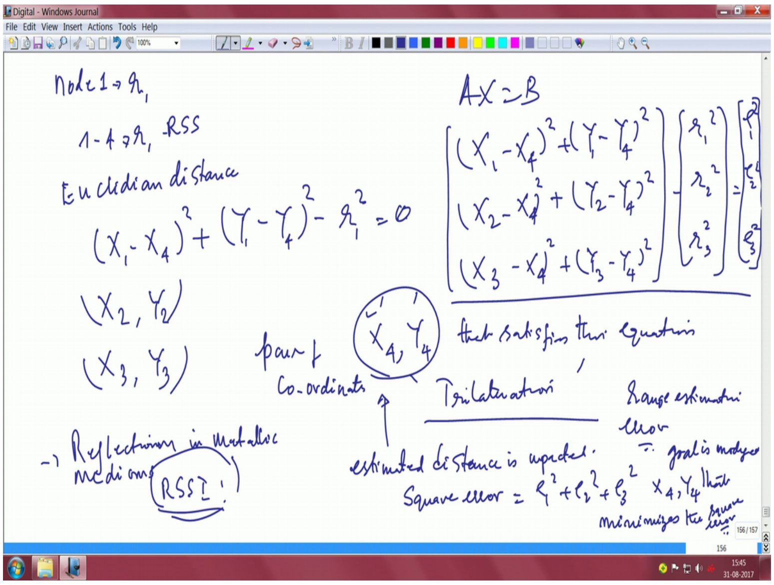

Now, you can use this very effectively in the following way. Take node 1 you can estimate the distance r 1 from 4, distance it is r 1 from between node 1 and 4 node 1 and 4 is r 1, this is the distance, right. Using this RSS. So, you get one RSS like this right.

From the single measurement done by node 1, the only conclusion that can be made is that node 4 is located on it is perimeter. Would you agree? It is located on it is perimeter. So, let us show it quickly it is located on it is perimeter you can say that, right. Is what you can say oops. You can say do not want to oops. It is not a good way to keep it rising, you can say that. The only conclusion that can be made is that it is on the perimeter of a circle with radius r 1 centered at node 1, I have not shown it properly, but excuse me for that.

We should show it with the centre there, right. Something like this centre. Now what you can do is you can use simple Euclidian expressions Euclidian distance expression Euclidian, Euclidian distance expression and we can write a very simple one X 1 minus X 4 the whole square, plus Y 1 minus Y 4 the whole square is r 1 square. I hope you will appreciate that this is situated in X 1, Y 1 and this is in X 4, Y 4 that is the idea, right. X 4, Y 4, 2 dimensional only we have taken.

Similarly, you can take this r 1 square on the left hand side and make this equal to 0 and all of that, we can take that and make it equal to 0. You can derive other equations also you can derive for X 2 Y 2 and for X 3 Y 3 you will get r 1 r 2 and r 3, right. R 1 square r

2 square and r 3 square. You can put them down in a nice matrix representation of A X equal to B. And that is quite simple X 1 minus X 4 whole square plus Y 1 minus Y 4 the whole square X 2 minus same X 4, right. Y 2 minus Y 4 whole square, X 3 minus X 4 whole square plus Y 3 minus Y 4 whole square, right. Minus r 1 square r 2 square r 3 square equal to 0 correct. So, in the ideal scenario which is what we are saying you should be able to you will get. So, basically there will be a pair of coordinates X 4 Y 4 that satisfies this equation. So, there will be a pair, right. That satisfies this equation.

So, I will write that down there will be an pair X 4 Y 4 pair of coordinates that satisfies this equation and that is all that you need to know, need to do. If it satisfies this equation that value X Y X 4 Y 4 is the location of the node 4 that is all and this method of determining the relative location of nodes this method is actually called trilateration trilateration. The trouble is you know, you will never get X 4 Y 4 very accurately. The problem is it fluctuates. So, it is very hard using RSSI methods to actually fix on what is X 4 Y 4 that is indeed the biggest limitation of RSSI there are other. So, it impacts the accuracy it impacts the estimated distance the estimated distance is impacted maybe estimated distance is impacted because of the fact that there is a lot of inaccuracy in the measurement of RSSI as provided by the systems. So, you cannot even believe that indeed that the RSSI that it reads is exactly what it should, because then your equation this satisfying this equation becomes difficult.

So, what normally you would say is there is a certain error associated with the range estimation error is there range estimation error which is range estimation error. What are we trying to ultimately lead you to? What we are saying is because of reflections, because of reflections in the in metallic mediums wherever you have position the reader tag environment all of that does not give you a stable RSSI reading at all you, will never get a stable RSSI value. And if we do not get stable value there is no way of fixing satisfying this equation, and there is going to be an error ok.

So, practically use of RSSI is difficult, that is one thing. Another reason why then let me just finish this. So, that is one part why RSSI is hard, but then there are ways by which So, what you normally do is you do, not really say that it is equal to it satisfies this condition equal to zero, but you could perhaps say that it satisfies some error e 1 square e 2 square and e 3 square, you do not make it zero, but you say it satisfies some e 1 square e 2 square and e 3 square error in the measurement from each one of the nodes.

And what you do is you try and do some square basically this e 1 square e 2 square e 3 square is nothing but the square error square error which is nothing but e 1 square plus e 2 square plus e 3 square. And then you say the goal is location estimation that it minimizes this error square error. Now you modify the goal, goal is modified. And now you go ahead and say I will because I have a problem with this RSSI in it is measurement accuracy because of several reasons.

I will now modify the goal and the new goal now becomes estimating estimation we have to find this X 4 Y 4 that minimizes to find X 4 Y 4 that minimizes that minimizes the square error. This is all you can do you can never get it to 0 that is the point ok

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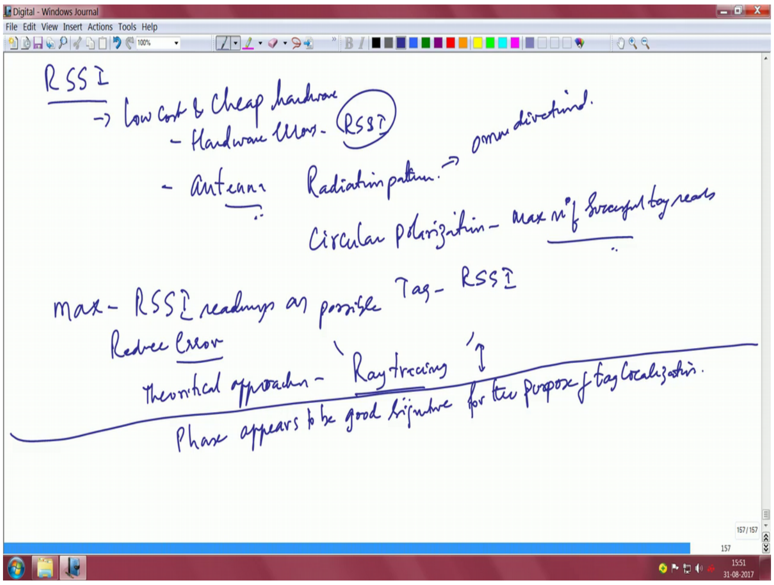

I must point you to some other reasons why RSSI is not a good idea, why RSSI is not a good idea? It is because you can have you can have, because these are all I would say low cost low cost and cheap low cost and cheap hardware. Because they are low cost and cheap hardware you can have hardware errors ok.

And these hardware errors can read different RSSI is on different tags. You can have different RSSI So, RSSI can be because of that. Another thing is antenna what did you assume? You assumed that it is a so, look at the radiation pattern and go back to what we said, right. How are you sure what is the polarization of the antenna? You would expect good tag reads you would expect maximum number of tag reads if the antenna pattern radiation pattern is circular, circular radiation circular polarization sorry, circular polarization circular polarization means you will get maximum number of successful tag reads maximum number of successful tag reads.

Here with respect to RSSI this is not the challenge. The challenge is you will get a lot of tag reads, but each of the value each of the time you read the RSSI each time you read the tag the corresponding RSSI is fluctuating, that is indeed the challenge so and various reasons why that is an issue. And radiation pattern you can never assume that the radiation pattern indeed is Omni directional. You can never make an assumption about that how are you sure maybe it has a lobe which is extending quite a bit in one direction, but in the other direction the lobe perhaps is not extending too much. Then in which case it can have issues related to reading RSSI accurately. That is one thing. Then So, I mentioned about Omni directional; so radiation pattern.

So, radiation pattern affects the signal strength and therefore, will affect the RSSI alright then, so what is the way out? Some if you keep asking this question what is the way out, the way out is get as many RSSI readings as possible. Read as much as many RSSI readings maximum RSSI readings as possible and then you take. So, you increase over a long period do multiple times somehow you reduce the error by repeating with experiments, by reading it for long durations of time and then observing some pattern and then somehow you reduce the error ok.

So, that might be one way of let us say using still continuity use RSSI for the purpose of localization. Then there are other ways there are other theoretical approaches, theoretical approaches. And very popularly there is something called ray tracing, ray tracing methods by which you estimate the indoor environment floor plan reflection coefficient of surrounding materials. And you use as much as other information as possible. And use that put that use all of that and then arrive at some way of fixing the RSSI value. So, this is in brief what you can do with respect to RSSI.

Finally, you also should know that face appears to be good signature available from most RFID readers for the purpose of purpose of tag localization. Let me show you a picture of what we mean by phase of the tag and with that we will understand a little better about how to extract this phase from the, how to how to use the phase is already available from the reader every time it reads a tag, and how to use that phase in a manner that we will be able to use it for localization. So, we said phase appears to be a good signature for purpose of tag localization.

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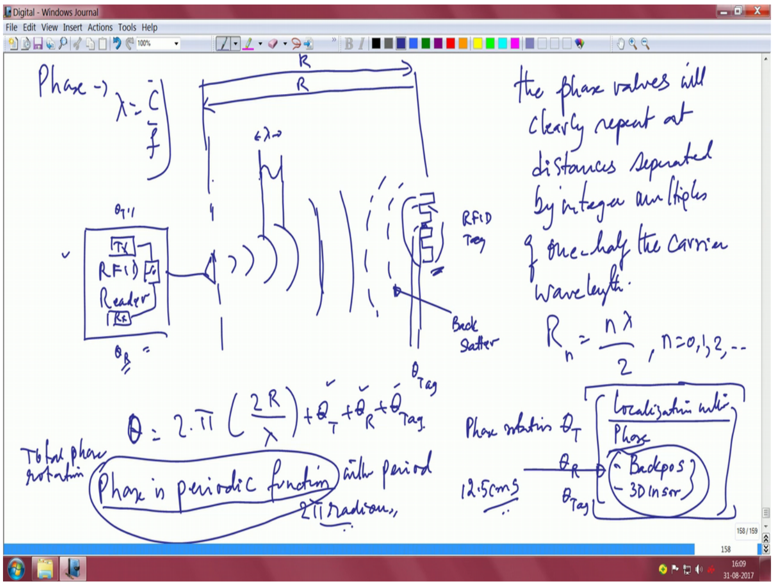

Let us see that here. In this picture what I have done I have shown you a reader this is the RFID reader this is the tag use the tag on this side this is the tag. And this is the reader they are separated by some distance r. And a wave which travels from the transmitter antenna RFID reader antenna goes all the way up to travels, this distance r and gets back scattered to another distance r right. So, 2 r is the total distance travelled by the wave I have shown this dotted line to indicate that this is really back scatter, this is important. Tag is back scattering the data, right. Because it does not have a battery by the way when we say battery I keep saying this there are basically 3 types of tags, right.

There are something called active tags there are passive tags and there are battery assisted passive tags. These essentially have batteries and they are another class of RFID tags. Please look them up carefully to understand how these tags are different. So, I am just saying that there are 3 different types of tags you just keep note of that. So, here in this case what I have taken is a completely passive tag and it is doing a back scatter of the information, very good. As you know this is lambda is simply given by c by f c is the velocity of light f is the frequency of operation and this is the lambda right.

So, essentially the total phase theta is nothing but 2 pi times this 2 r by lambda plus Q T Q R and theta tag sorry, not Q I mean, theta T theta R and theta tag. What I mean by this theta T R and this theta is nothing but, the phase rotation phase rotation. When doing a transmission gives you theta T when you are receiving you get theta R. And the tag itself will have a theta tag as a phase rotation. Theta T and theta R will manifest themselves at the reader side whereas, theta tag you manifest from the tag side. No why the good thing about phase based localization is, the phase itself is a periodic function which period 2 pi radians the phase values of course, will repeat at distances, ums separated by integer multiples of one half the carrier infra wavelength.

But that is, but you will be able to because the fact that this is a periodic function, it is a lot more stable for you to do localization to complete localization with phase. And I would point you again to paper such as back pause and 3D insar which essentially build on use of the phase based approach, and do and perform localization using and come to very accurate localization of RFID tags. You can have mechanisms where you can use single antenna or you can use multiple antenna.

When you go to the multiple antenna case it is quite simple quite similar to RSSI where we show the 3 nodes receiver nodes and one and you are trying to fix the location of the fourth node, it is very similar, right. You basically use multiple antenna and you try to get the phase information from this multiple antenna and then you do a trilateration equivalent, and use simple geometrical techniques and you do you can and basically you can do a phase you can look at the you can localize the tag using the phase. Another approach is you can use a single antenna and try also localization.

So, these papers essentially are very are recently published articles where they discuss about the localization of RFID tags using phase based approach. It is a very rich area of problems and exciting solutions are available for people to look up, when they when they use phase and In fact, very stable localizations are possible. In fact, back pause says that it can localize tag to an accuracy of 12.5 centimeters which is pretty good for many applications. So, that is broadly what the localization challenge with the RFID tags are all about.