Introduction to Internet of Things
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Lecture - 16
Sensor Networks- III

In this lecture, I am going to talk about some of the applications of sensor networks. So, sensor networks as I said in a previous lecture can be used for serving different applications agriculture, healthcare, space and so on and so forth. Many different types of applications are possible. So, we will take up few of the applications where sensor networks can be used and also keeping in mind some of the research works that we have done in our Swen lab at IIT Kharagpur and so that I can give you a little bit of more insight about you know house sensor networks can be used to address different problems of different application domains.

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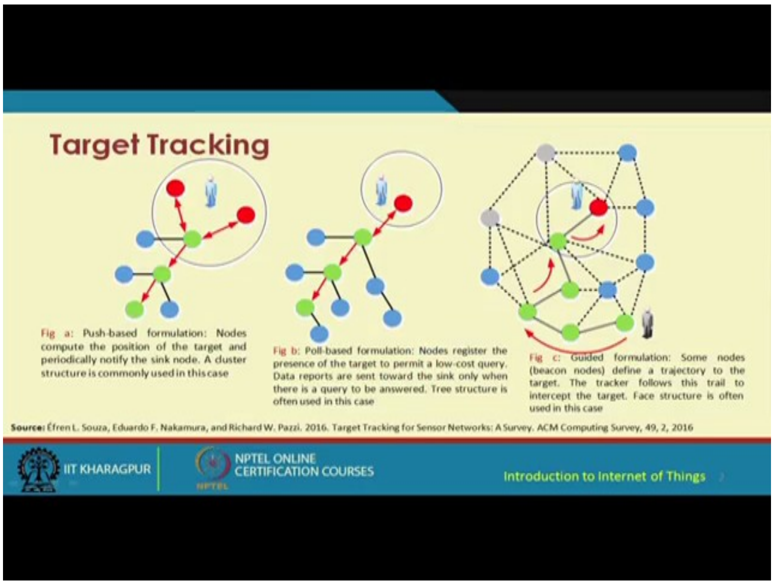

So, the first thing that I am going to talk about is the problem of target tracking. So, let me explain to you what the problem of target tracking is.

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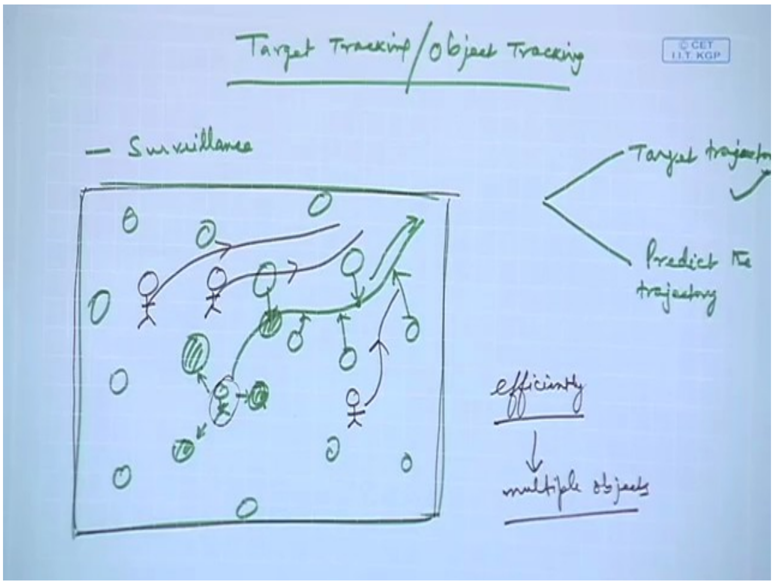

So, let us say target tracking, this is also known as object tracking. So, what happens is sensor networks are very much useful for surveillance applications, surveillance applications means that we can use different types of sensors, we can use cameras we can use a combination of all of these sensors cameras etcetera. To track a particular object a particular target maybe there is some suspicious activity that is going on maybe in a public place like a railway station or maybe in a crowded place some plaza or some market place or something like that.

So, sensor networks can be used for surveillance application. So, if there is already some sensor infrastructure that is deployed in a particular place. So, these sensors can be used to first of all identify that there is something wrong that is going on. So, you need to have appropriate sensors of course, and thereafter once it is detected that there is some suspicious activity that is going on then to track the trajectory of the target. So, this tracking can be of 2 forms. One is that as and when the target moves we keep on we keep on following the target using these different sensors we keep on sensing, where and how the target is moving.

So, that can be done in real time. The other possibility is that to predict the trajectory of the target. So, predicting the trajectory of the target. So, it can be of 2 types. Now what essentially I in either of these cases what essentially happens is we have different sensor nodes. These sensor nodes are placed all over in the terrain where monitoring has to be done. Now let us say that there is an object maybe a human that has been detected by these sensors these 3 sensors - this one, this one, and this one. So, the problem of trajectory sorry target tracking is that when this target moves the trajectory of that particular target has to be followed by these different sensors on the way. So, this is what this is this particular problem

The second problem is to predict the trajectory. So, prediction means that let us say that this object has been identified here in this particular position by these sensors it moves to the next location the next location is let us say here and then these sensors have detected this particular target like this it keeps on moving etcetera it comes to this particular position and then at this position we have to predict that what is going to be the next particular position or a sequence of positions of the target. So, we have to predict the next position or sequence of positions of this target. So, this is known as the problem of target tracking in sensor networks.

So, going back, we have different types of formulations of the problem of target tracking. One is the push based formulation, which is about that nodes computing the position of the target and periodically notifying the sink node. So, you know if this is a sensor network deployment, then you know this particular target this object has been identified by these sensors have been sensed, by these sensors, and then these sensors when this object moves it is going to compute the position of the target and then periodically at certain intervals of time notify to the sink node in this case, let us say that this is the sink node. So, it will be modified to this particular sink node.

So, sink node is the one which basically gets all the data from the other nodes the source nodes and the intermediate relay nodes. So, this is the sink node leadership. Now the other formulation is known as the poll based formulation which is shown in the second figure over here. So, in this particular formulation what we have is nodes registering the presence of the target to permit a low cost query. So, in other words the nodes are going to send out are going to poll all the other nodes to see if there is any object that is there in their locality; that means, within their sensing range. So, this is the poll based. So, it is going to periodically it is going to polled.

So, every node is going to be polled periodically. And the third is where there is a tracker that is used. So, tracker basically follows the trail of the target and intercepts the target.

So, this is known as a guided formulation. So, we have 3 distinct types of formulation of the problem of target tracking in sensor networks. The next point that I would also like to highlight is that targeting is actually very important for sensor networks target tracking applications like surveillance etcetera are very attractive. And that is why there has been lot of research on target tracking or object tracking in sensor networks lot of research in our research group also we have done a lot of work on target tracking.

And so if you are interested you know you can visit my website and can get access to these papers research papers, but without getting into the research details let me also highlight another particular aspect.

So, let us say that we have going back we have a terrain like this. So, in this particular terrain in the previous example, I had considered that there is a single target or single object this human like this. There could be other objects as well and this is quite natural or this is quite typical in most of these applications because normally you are not going to track a single object normally it is going to be like there are multiple objects.

So, tracking multiple objects is it even more difficult problem, then single object tracking multi object tracking is even more a difficult problem than multi objective and that is quite obvious, I do not need to really elaborate am about why it is. So, so this multi object tracking one way is that individually you keep on tracking all the other objects as well, but that is not efficient. So, the problem is that how to efficiently how to track multiple objects in a terrain. So, now, let us move to the second slide where we have to understand how this target tracking basically functions.

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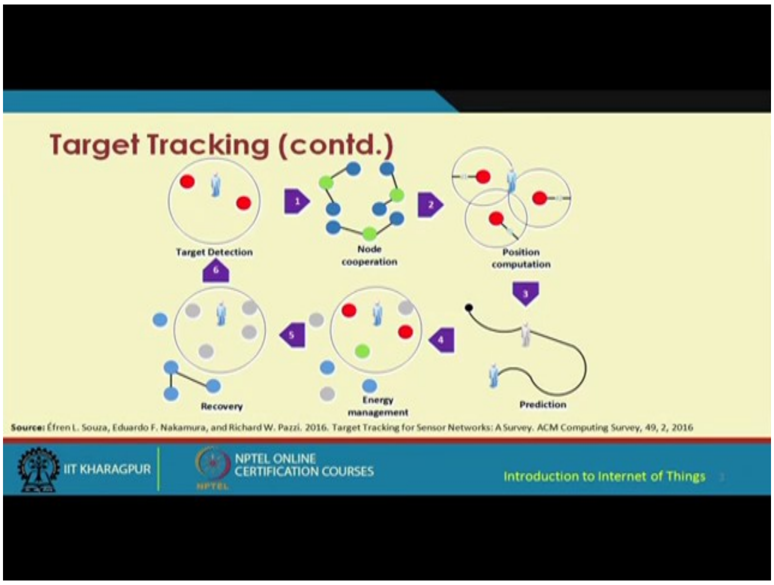

So, first let us say that you know we have different sensor nodes. This sensor nodes they have an object in their position in a close to them in their sensing range. Now what has to happen is the different nodes have to do lot of cooperation, for different purposes maybe for aggregating the data maybe for relaying the information that has been received about the tracking from other nodes, who have actually detected the presence of the target or who are following the target and so on and so forth. So, like this lot of different types of cooperation has to happen.

And then what happens is the position the exact position of the target has to be computed and this can be done using different ways, the position computation can be done in different ways for example, using the concept of trilateration using the concept of trilateration. If we know the positions of these 3 different sensor nodes we can easily compute the position of this particular object which is within the sensing range of these 3. Then after that there has to be some prediction that has to happen. So, prediction is about that if the object is at a particular location at this part at a certain instant of time, then at the later instant of time after delta t time, let us say where the object is going to be. So, let us say that the object is going to be over here.

So, this particular position has to be predicted and thereafter issues such as energy management etcetera have to be taken care of because it should not happen that large number of sensors basically are activated and they all start sensing. So, what is the minimum number of sensors that are required in order to efficiently track the target first of all identify the position of the target and then track it. So, activating those sensor nodes, and those few sensor nodes and basically putting the other nodes to the sleep mode which is basically a low resource consuming low energy consuming mode of the sensor nodes.

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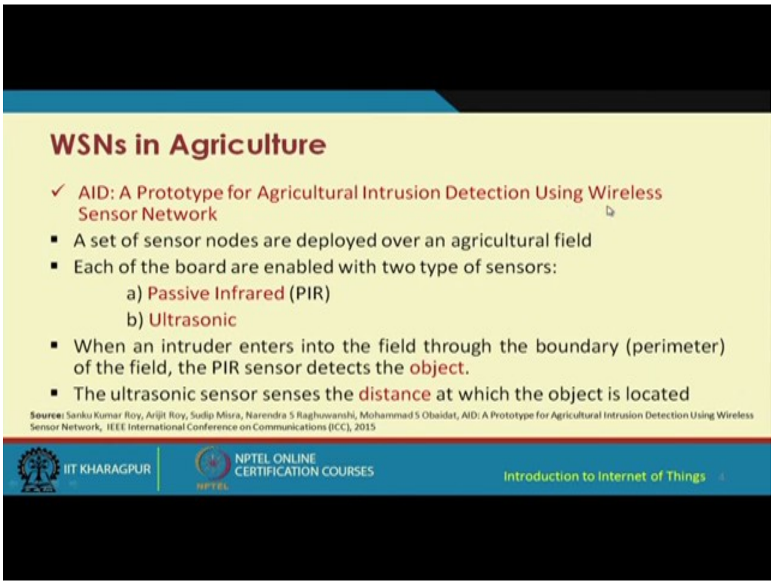

So, this is another energy management problem that also has to be addressed alongside the problem of target tracking. So, I told you about the problem of target tracking like this sensor networks can be used for various other applications as well it has indeed been used in our research group apart from different other applications, we have particularly focused on the use of sensor networks in agriculture. So, in agriculture we have basically focused on number one, surveillance of agricultural field.

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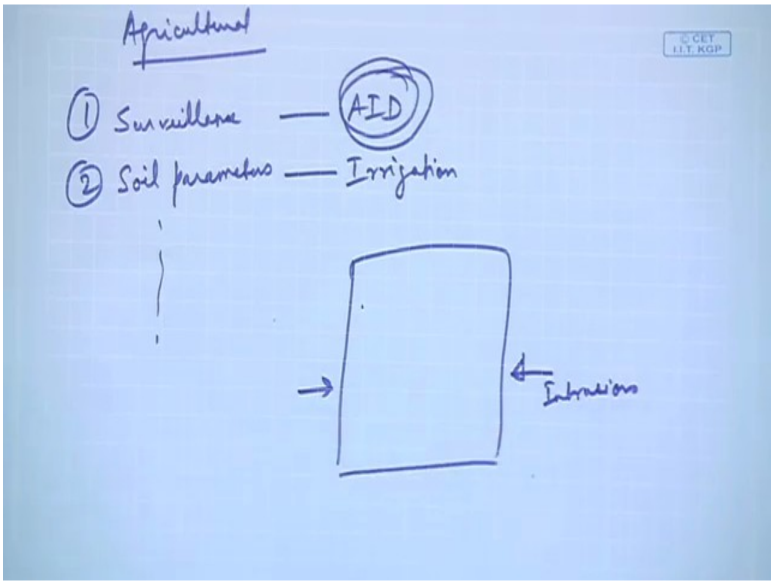

So, this is basically agriculture agricultural applications, we have also done some work on the use of sensor networks in the agricultural field for monitoring the soil parameters the soil parameters. So, for example, moisture content water level content and many other parameters for example, the mineral content of the soil phosphorus nitrogen and so on. So, these can also be sensed. So, soil moisture water level etc they can be used they can be sensed and that information can be used for irrigating irrigation of the field. So, if the soil moisture of the particular field has gone down we can irrigate the field and so on. So, like this actually there are different types of applications in surveillance we have worked on monitoring if a particular agricultural field is protected from intrusions, from intrusions from let us say cattle like you know cows goats etcetera because normally you know this is a very typical problem in a country like India where we have different cattles and different animals getting into the field damaging the crops and so on.

So, this kind of surveillance of the field is also very much required. So, so this kind of intrusions have to be detected and this can be done with the help of this technology the system that we have developed which is known as the aid. So, aid is basically a prototype for agricultural intrusion detection using wireless sensor networks, we are using 2 types of sensors the passive in infrared sensor the PIR sensor and the ultrasonic sensor. So, when an intruder basically enters the field through the boundary of the field the PIR sensor detects the object; that means, the intruder and the ultrasonic sensor basically senses the distance at which the object is located.

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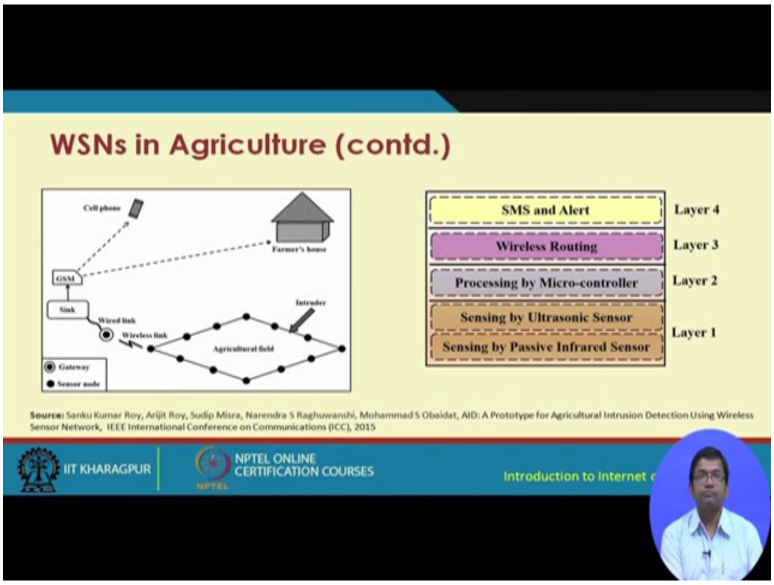

So, this is why these 2 different sensors are used there is sensor whether it has the entered or not and the ultrasonic sensor about how far the object is from that particular sensor. So, this is the schematic diagram. So, this is the agricultural field and an intruder getting in these different sensors are deployed in the perimeter or the boundary and the sensors will detect whether there is any intrusion that is going on or not and if it is going on then the farmer is going to be notified through cell phone or through other means at his home or wherever he is this is the layered architecture of this particular system that we have developed. So, first 2 layers are sensing using PIR sensor and the ultrasonic sensor.

And then processing by the microcontroller and then routing and finally, the application level SMS and alert messages will be sent to the farmer or any other stakeholder of that particular field.

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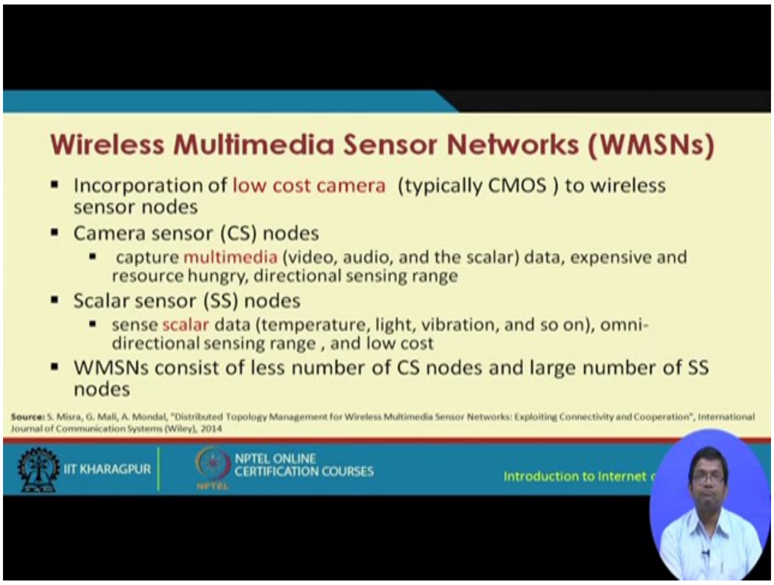

So, this is one application that we study the second definitely, the first is basically target tracking second is agriculture and in agriculture what we have just gone through is detecting intrusions in agricultural field, we could as I told you also that we could use sensors different types of sensors to measure to monitor the soil conditions with respect to moisture content water level content and so on and so forth. And correspondingly if let us say the soil parameters have gone down or is below a certain desired level then the field is going to be irrigated. Now let us look at something known as the multimedia sensor networks, multimedia sensor networks is very interesting in the media sensor networks.

We use multimedia devices apart from the regular sensors, these regular sensors like temperature sensor humidity sensor soil moisture sensor etcetera. These in multimedia sensor network technology in the community is known as scalar sensors, these sensors are known as scalar sensors. And in addition we have the camera sensors the camera sensors basically include like steel cameras in the small sized steel cameras or video cameras, which can be integrated along with these scalars scalar sensors to get a complete picture of what is going on in a particular area of interest.

So, typically what would happen is, we would be very much interested to get a complete picture and for getting complete picture ideally we should have cameras everywhere which would take still images and so on, but that basically is not only expensive having too many cameras deploying too many cameras in a field is not only expensive, but also that is not a very good solution from a network point of view, because if we have too many images of big size being taken then these big images big sized images are going to float all over in the network. And that is going to be not a very good solution for a resource constrained more specifically a bandwidth constrained environment like a sensor network.

So, the whole idea is can we use large number of these inexpensive cheap low cost sensor scalar sensors and have a fewer camera sensors, and together we can we have a better surveillance. So, how it is going to happen I will show you.

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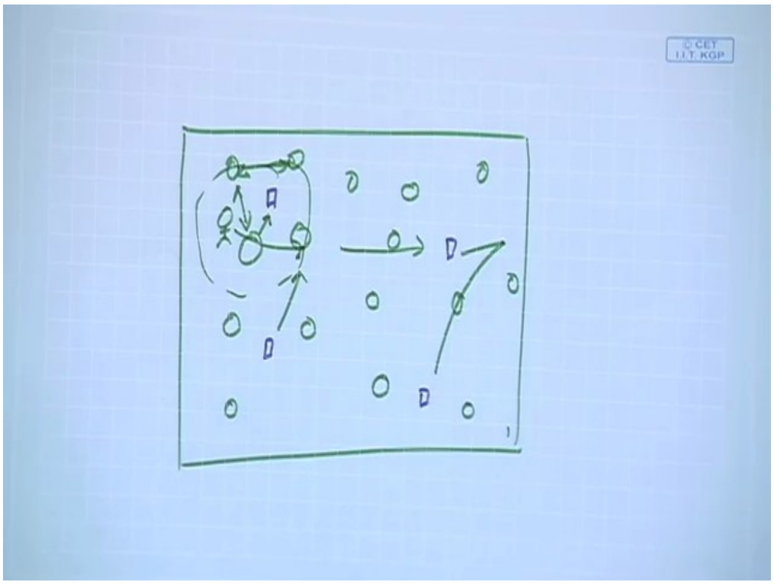

So, let us say that we have some terrain of interest. So, here we can have these different scale sensors all over which can be something like temperature sensor, humidity sensor, soil moisture sensor or whatever depending on the application that we are targeting and within this we would be using.

So, these are the green colored circles basically denote the scalar sensors and then we would be using only very few cameras. So, these cameras are expensive. So, we cannot use too many of them and also from a network perspective, as I said before we cannot use too many cameras. So, what is going to happen first these cameras these scalar cam sorry.

Ah these scalar sensors they are going to detect whether there is something going on or not, and thereafter if indeed there is something some suspicious activity or something going on and is detected by these scalar sensors through their collaborative sensing, then these sensors are going to activate the camera and this camera is then going to servile.

What exactly precisely is going on? Similarly the other cameras could also be activated depending on the position of the particular object, and how it is moving in the particular field. So, this is how the camera and scalar sensors putting together can work collaboratively you know wireless multimedia sensor network.

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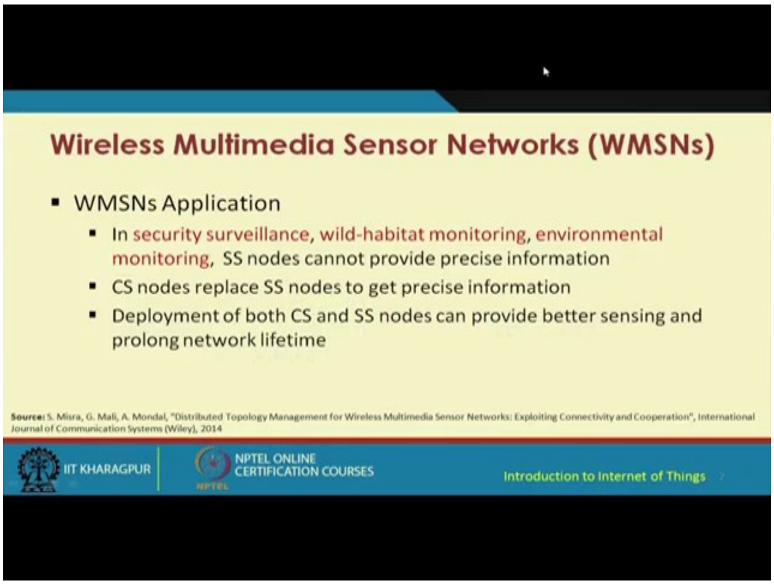

So, there are different applications of multimedia sensor networks surveillance is something that I was talking about right.

Now, but we can also have wild habitat monitoring like you know wild habitat monitoring means, like you can have these multimedia sensor networks to track precisely and monitor, how the different wild animals in their natural habitat are moving how what activities they are doing whether they are healthy or not and so on and So, forth environmental monitoring likewise and so on. So, like this actually there are different types of applications of multimedia sensor networks.

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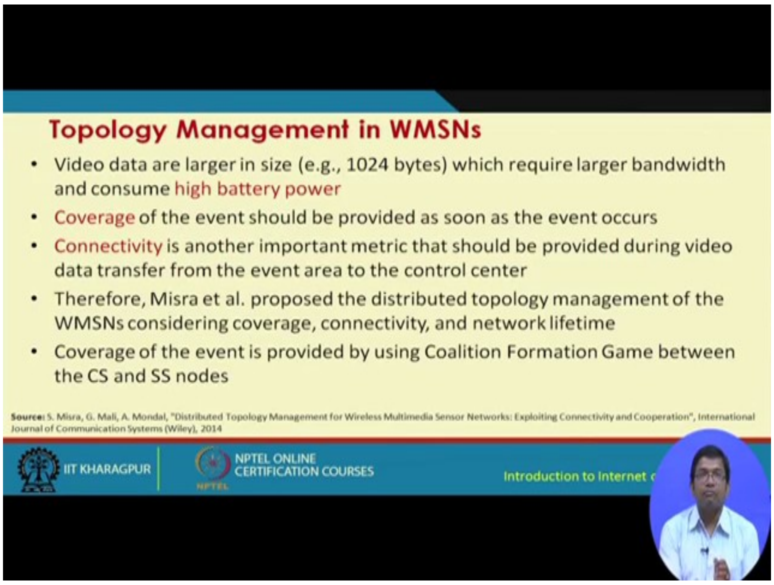

Topology management is another very interesting problem. In topology management what happens is that in the presence of these different sensors and in our particular case we are talking about multimedia sensors. In the presence of these multimedia sensor networks and these different sensors.

How the topology is going to be maintained over time, how these sensors are going to connect with one another over time, whether they are you know whether with respect to coverage means that with different sensors whether the entire region of interest is covered by at least one sensor or not. So, with respect to coverage and connectivity means that from every sensor whether there is connectivity to the sink node or not, so with respect to coverage and connectivity, whether at different instants of time the network is has a healthy topology. So, this is what is taking care of in the problem of topology management. And this is this is one paper that is there for you as a source which you can go through to understand the problem of topology management in sensor networks.

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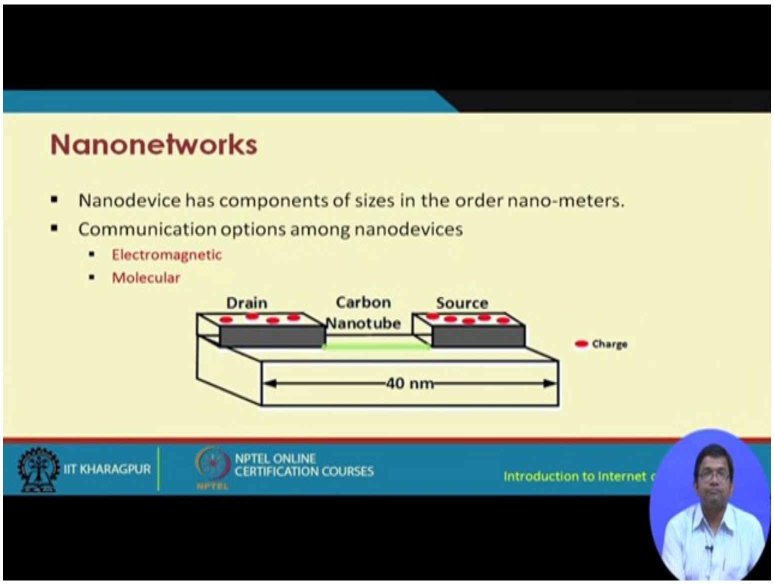

Another application and a technology that has evolved over time is nanonetworks. You must have already heard about lot of interest in nanostructures, nanomaterials, nanodevices and so on. And in including nanosensors, but you may not have heard about nanonetworks.

So, narrow networks more specifically nanosensor networks can be of 2 types. One is the electromagnetic nanosensor networks the other one is the bio nanosensor networks. So, the electromagnetic nanosensor networks basically as the name suggests the communication is through electromagnetic means and the other one is by nanosensor networks where basically it is biomolecules that help in communication in the human body or any human or you know any other natural being. So, nanodevices are used for as nodes in a nanonetwork on a nanosensor network. And every nanodevice has different components like one of which is the nanosensor, nanoactuator nanopower device and so on and so forth. So, this is how the communication takes place and between the source and source device and the sink there is going to be over the nanomedium such as carbon nanotubes there is going to be flow of charges that is going to take place and as you can see over here this is in the scale of few nanometers only. So, as you can understand one issue over here is to first design or fabricate nanosensors. Similarly it is also required to design and fabricate other nanodevices like nanoactuators nanopower sources and so on. And then the other problem is how we can put the nanosensors nanoactuators nanopower devices.

And the like together as a single device then nanonode and this nanonode also has a nanocommunication unit and this communication unit of one nanonode would help to connect with another nanonode with a similar kind of receiving device, and this communication in nanoelectromagnetic networks takes place in the terahertz band so this is typically this communication takes place in the period spent in nanonetworks.

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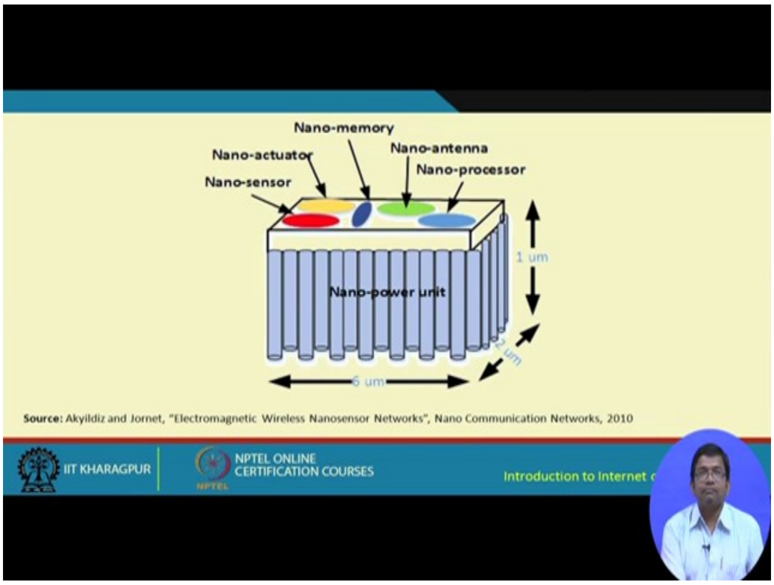

So, this is what I was telling you. This is a schematic of how a nanonode looks like. So, we have this nanopower unit, we have this nanosensors actuators nanomemory nanoprocessor nanoantennas for communication and so on and these corresponding dimensions are also mentioned over here. So, this is like 1 micrometer 2 micrometer 6 micrometers and so on. So, this is a very small kind of you know extremely small scale nanoscale node, which has to be fabricated not using conventional sensor node design mechanisms, but using a very sophisticated mechanism that is that takes help of nanofabrication units nanofab fabrication facilities.

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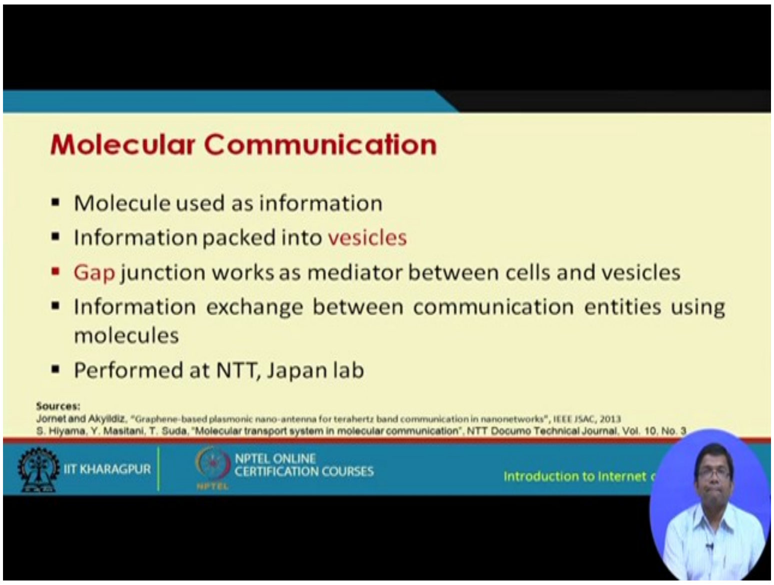

So, earlier I was talking about this nanoelectromagnetic communication. I also mentioned that bio nanonetworks are possible where the communication takes place through molecular exchange. So, information in this kind of a bio nanonetworks is basically packed into something known as the vesicles. And the gap junction works as a mediator between the cells and the vesicles and the information is exchanged between the communication entities using the molecules.

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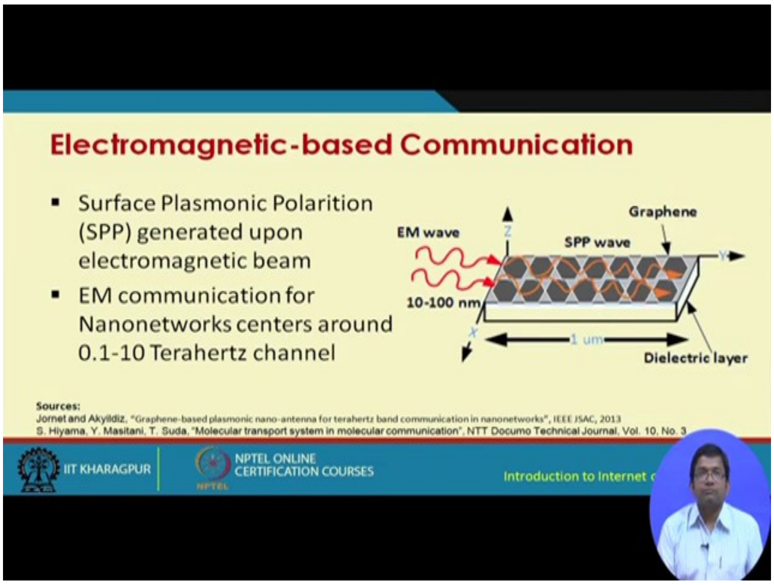

So, in the electromagnetic communication, something like this happens you know it is basically electromagnetic waves that basically are passed through some kind of nanomaterial like a grapheme or something like that and the information is transferred from one device to another device.

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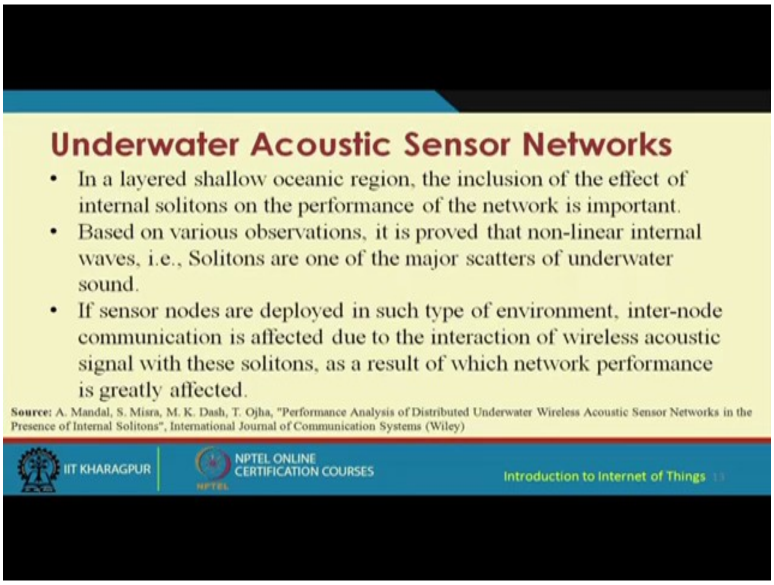

So, great magnetic communication for nanonetwork centers around the 0.1 to 10 terahertz general band. Then we have underwater acoustic sensor networks where basically it is about submerging conceptually submerging the sensor nodes that we are familiar with. So, far in the underwater domain submerging them let us say in the ocean and then having them sense and communicate to retrieve the information from under the surface of water. So, this conceptually is very simple and is similar to what happens in the terrestrial sensor network domain.

However in practice achieving and underwater sensor network fabricating a underwater sensor node and then connecting those nodes to communicate underwater to sense and communicate underwater is a hugely challenging task and there are so many different challenges that have to be taken into account. The first thing is the mobility the mobility because of waves and currents underwater the nodes wants to deploy them at a particular point, they are not going to maintain their position subsequently they are going to move all around.

So, how do you maintain the topology of the network in the first place second thing is that with respect to communication when these different waves are hitting these different nodes, then they are also affecting the communication channel the channel are is also going to be affected. So, in such kind of noisy environment how the communication is going to take place also. In addition we have the medium which is typically like saline in nature where there is lot of temperature very in the ocean column where there is lot of pressure variation in that ocean column. So, all these also affect the communication channel and the performance of communication in such environments.

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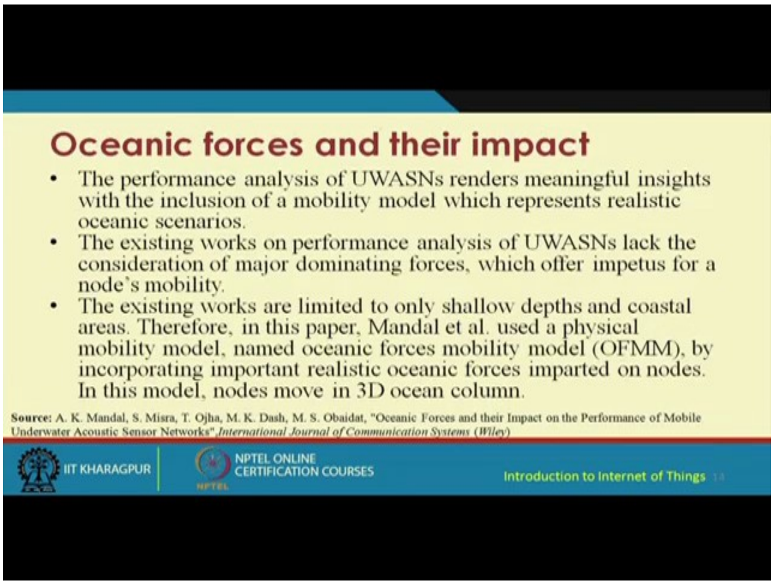

So, different oceanic forces also have impact on these networks, and that is the reason trying to simulate trying to simulate an underwater sensor network and it is environment is not very easy. So, one of the important concerns about simulation is that how the nodes in an underwater sensor network are going to move.

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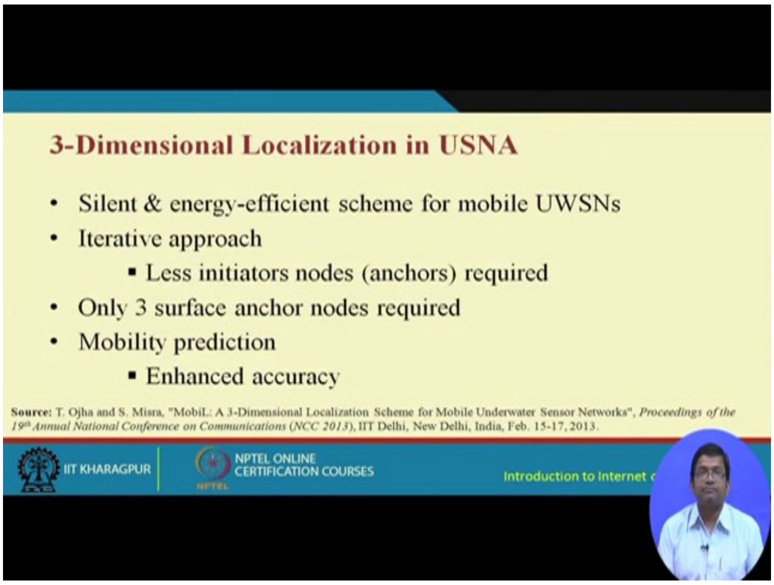

So, for that there is a mobility model that has been proposed, and this is known as the there are different mobility models one of which is the meandering current mobility model. So, this meandering current mobility model was proposed in a paper that was published in infocom conference several years back. And thereafter we have proposed in our group a mobility model which is known as the of mm oceanic forces model mobility model. And the characteristic of this particular of mm mobility model is that we have taken into account the realistic forces that are going to hit a particular node in a in an oceanic environment, whereas, the meandering current mobility model that do not take all these different forces.

That we have considered and this is how we have come up with this OFMM mobility model and this can be used to simulate the behavior of underwater sensor networks.

Localization is another problem localization problem is concerned about that how to localize the different nodes in the network and as I said that underwater environments highly dynamic highly chaotic, and localizing the position of the different nodes is highly challenging as well. And there are again lot of works that have been conducted on this particular problem. So, it is important to predict how the different nodes are going to move at different points of time accurately. So, accurately finding out that at a particular instant of time in the future where this node is going to be is a challenging problem of localization in underwater sensor networks.

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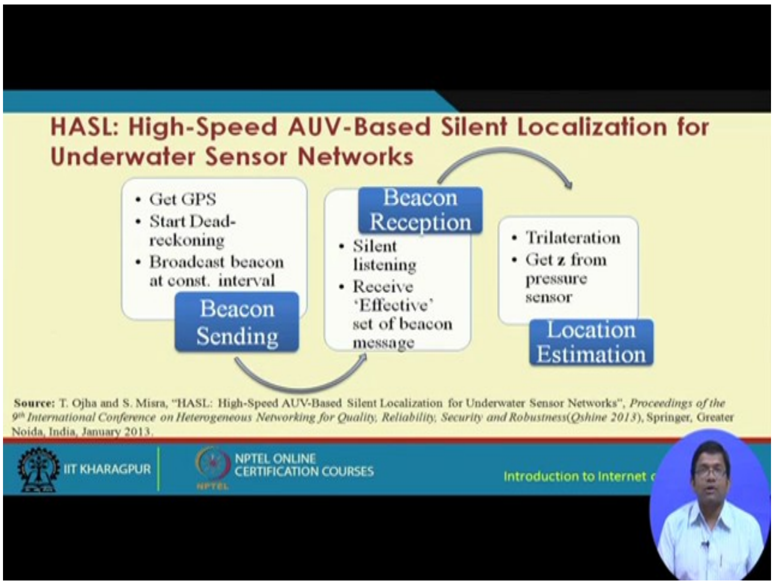

Protocols such as HASL which use beacon sending beacon reception and location estimation information to basically localize the nodes. So, these are these start with first getting some GPS coordinate from maybe a surface sink, and then start processes like dead recording and broadcast becoming sorry broadcasting beacons and so on, receiving the beacons getting an estimate of location estimation through processes such as trilateration and so on. And this has been explained in detail in this particular paper that is referenced over here at the bottom of the slide.

So, dead reckoning I was mentioning to you about dead reckoning digitally is I mean it is a technique of localization that is typically used in oceanic environments where it is hard to find specific references. So, in dead reckoning what is done is based on the distance from a particular target or a particular node whose position is known. It is estimated how another node how much far another node is located and at what angle.

So, based on this distance and angular information the position of the target at different instance of time in a marine environment is basically computed.

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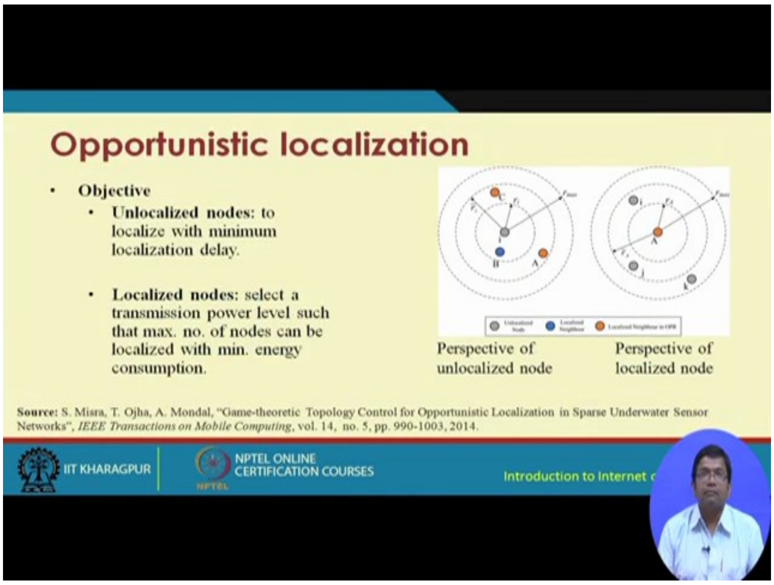

This is a proposal you know, this is a paper I triple e transactions on mobile computing it appeared. And here basically you know we are talking about how to efficiently localize with the help of advanced techniques such as game theory and so on.

So, here we have considered 2 types of nodes that are localized nodes and the localized nodes the problem is about based on the location information from the localized nodes how to get the location information of the unlocalized nodes. And for this what we do is we vary the communication range the transmission range of the of the of the nodes and by varying it the problem is to maximize the number of varying or increasing the increasing the transmission range, the problem is to maximize the number of nodes other nodes which can be put within that corresponding range the transmission range of a particular node. So, this is what is shown over here pictorially as you can see this particular node, you know it has an initial communication range like this the transmission range which can be increased further like these other circles.

So, these are the 3 different ranges that are shown of the communication range or the transmission range of this particular node likewise for the other nodes also it is shown like this.

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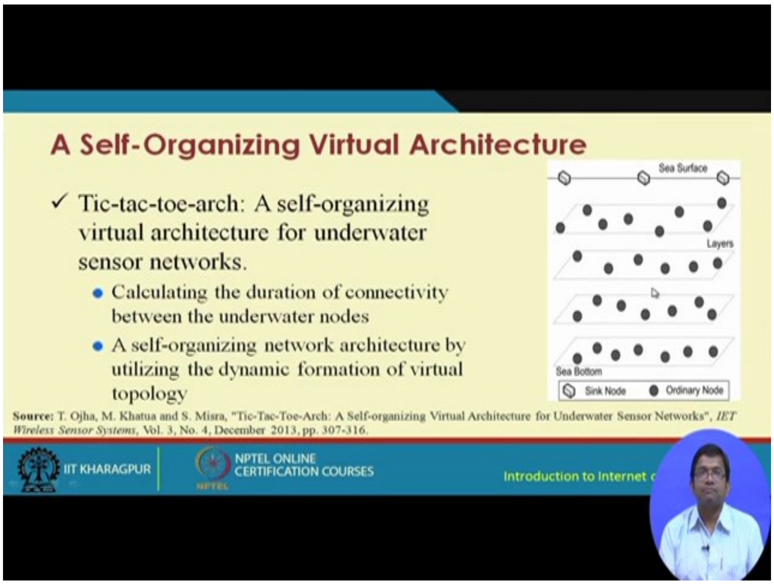

And the other problem is to maintain the topology maintain the architecture in underwater sensor networks for this there is this architecture, the tic tac toe architecture which is a self organizing virtual architecture has been proposed by us, in the iet wireless sensor systems journal and here. Basically what we do I am not going into the details of it because it is not required; I just wanted to give you a flavor of this particular problem because this is indeed very important and fundamental in the underwater sensor network community. So, it is required to calculate the duration of connectivity between the different the water nodes, and what we have done is we have to post this tic tac toe architecture, which is a self organizing network architecture by utilizing the dynamic formation of virtual topology.

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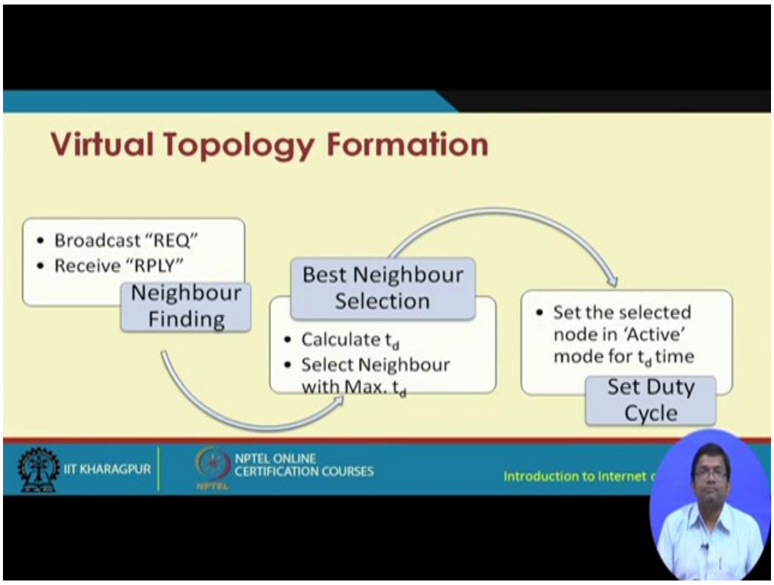

So, here there are 3 steps neighbor finding neighbor selection and duty cycle and duty cycle management. So, duty cycle management means that based on the computation of how much the nodes are separated from each other the other nodes and their corresponding duty cycles are set or reset accordingly.

So, with this we come to an end of this particular lecture and what I have tried to do in this lecture, is to give you a feel of the different applications of sensor networks and the different research challenges in order to address those specific applications. And so we have also gone through some of the high level ideas about how to address what are the different solution approaches to address those problems.

Thank you.