Wireless Ad Hoc and Sensor Networks

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Lecture – 23
WSN Coverage & Placement- Part- I

In the previous lecture on wireless sensor network we have seen, the basics of these networks sensor networks consist of sensor nodes as the fundamental unit is of deployment. And the sensor nodes have one of these components to give the sensor. And then there could be different types of sensors that could be used in these networks, and the type of sensor that is used depends on the particular application that the particular sensor network is serving. These networks can be use the sensor networks could be used for different applications wide range of different applications.

But what has to happen is for deploying these sensor networks, there are some fundamental considerations that have to be made. So, now, what we are going to cover are 2 very important issues, 2 very important problems the problems of coverage and the problem of problems of coverage and placement which we are going to understand and look at some of the solutions that have been proposed for these problems and we are going to understand them now.

So, first we are going to go through the problem of coverage. So, this particular part coverage emplacement has been segmented into 2 parts. In the first part we are going to go through the problem of coverage and it is solutions and in the second part we are going through going to we are going to go through the problem of placement and the different solutions for that particular problem.

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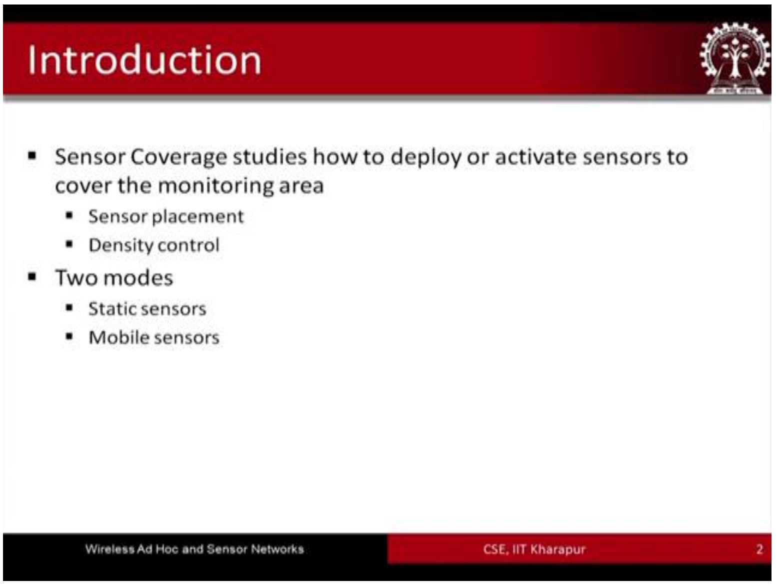

So, what is coverage? So, the problem of coverage basically talks about it is related to deployment. So, the sensor nodes have been procured or they have been designed and so on. And the sensor nodes have to be deployed in a particular area. So, they have to be deployed in a particular area so that that particular area each and every point in that area or each and every part or sub area is under the coverage; that means, under the sensing range of at least, if at least one sensor at least one sensor. So, this is, how we can have a particular region of interest let us say to simplify the problem because it comes in different dimensions and flavors.

So, the basic problem is how we are going to have a region of interest and how we can deploy the set of nodes. So, that we have in that region of interest. So, that the different sub areas of that area is within the range the sensing range of at least a node. So, how many (Refer Time: 03:28) the least number of nodes that we are going to have sensor nodes that we have with that we require. So, sensor coverage studies how to deploy, or how to activate the sensor solar this part. I am going to elaborate shortly or how to activate the sensors to cover the monitoring area in terms of sensor placement and density control. Density control means like you know how the sensors are going to be placed. So, that at one place you do not have too many sensors and where is at another place you do not.

You have very few sensors. So, at one place maybe you know dense deployment at another place you have a sparse deployment. So, in order to avoid, we have a general like you know a homogeneous kind of distribution of the different nodes. So, that the density is homogeneously controlled in that particular area of integral sensor placement. Basically talks about that how you are going to place these different nodes where you are going to place these different nodes, and how you are going to place these different nodes what are the different constraints under which the reasons are going to be made. So, this is the second part. So, we are not going to cover it now.

So, going back we have 2 modes of communication of the sensors 2 types of sensor nodes that I typically used the first one is the static sensor node, and the second one is the mobile sensor node the coverage problem when we are talking about mobile sensor nodes.

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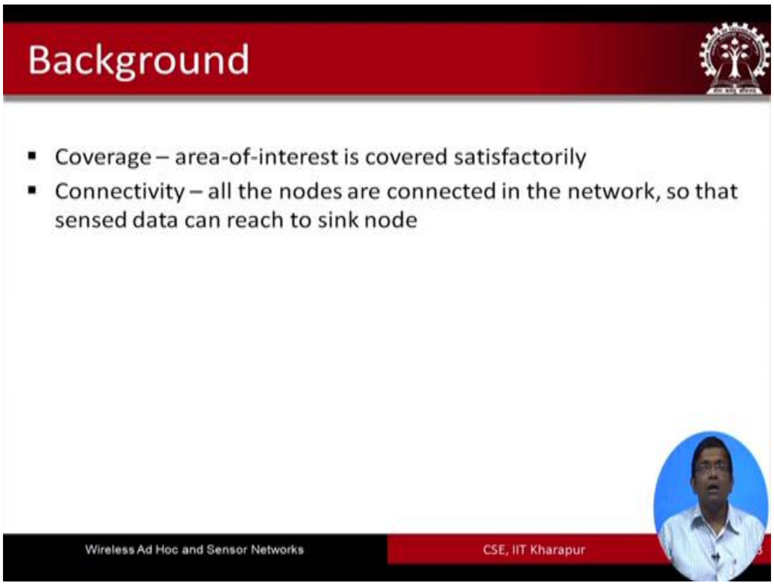

So, when we are talking about coverage, we have an area of interest and that area of interest has to be covered satisfactorily; that means, that at least one sensor if we are talking about a single you know one coverage problem then at least it should be under the you know under the region of under surveillance by at least one sensor node. There is another very allied or associated problem, the problem of connectivity. The problem of connectivity talks about that there has to be connectivity between the different nodes which has to be maintained. So, that sensed data can eventually reach the sink node. And as we will see little later that these problems of connectivity and coverage are linked with each other and sometimes it is sufficient to talk about and ensure coverage and automatically connectivity is also ensured.

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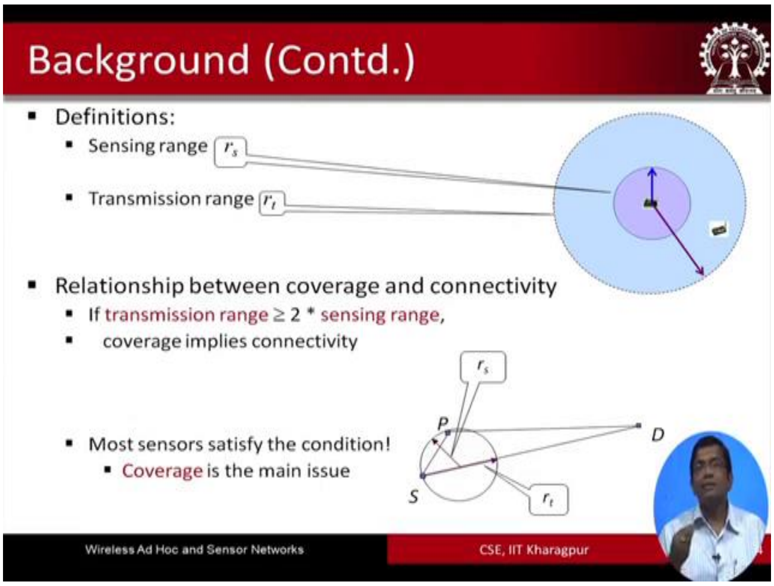

So, going to some of the basics we have to understand a few basic definitions. So, when we talk about a sensor node we talk about 2 different types of ranges. Any sensor node has any wireless sensor node has 2 different ranges. One is called the sensing range r s, the other one is called the transmission range r t right. So, and that is Quite obvious because sensing range talks about that how far a node can sense, how far a node can sense. So, in this particular example we can see that this particular circle denotes the extent to which this particular node can sense. And the bigger circle shows that how far the nodes which has sensed would be able to send the sensed information. So, we have to ensure that for if this is the range of communication.

From this for this particular node we have to ensure that there has to be another node somewhere which is going to collect that data that is transmitted by this particular node, at it receives it and through a multi hop path the data has to be transmitted to the sink node has to be related to the sink node or the base station. So, the few essential concepts, it has been shown in the literature that there is a relationship between coverage and connectivity as I said before. So, it has been shown that if we ensure that the transmission range of a sensor node is greater than or equal to 2 times the sensing range then coverage would automatically imply connectivity. So, in that case we do not have to bother about the connectivity problem we just have to take care of coverage problem and automatically connectivity will be taken care of. So, most sensors would satisfy this condition the most sensor.

Nodes that are available in the market basically satisfies this condition. So, that is the reason why coverage is the main issue that is studied when we talk about coverage and connectivity and connectivity is automatically taken care of when we ensure coverage of a particular area or a point of interest.

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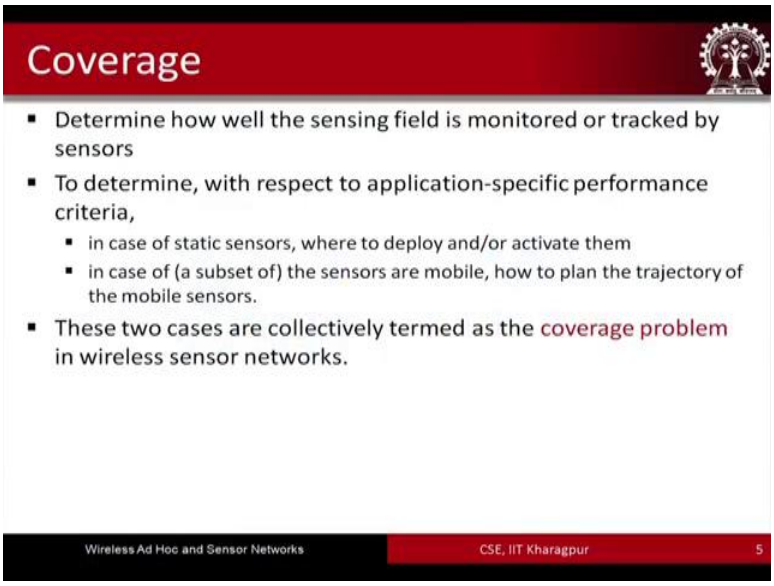

So, the coverage problem talks about determining, how well the sensing field is monitored or tracked by different sensors. And to determine with respect to application specific performance criteria that in case of static sensors where to deploy and or activate the sensors and in the case of multiple a subset of senses to be mobile; that means, in the case of mobile sensors how to plan the trajectory of these mobile sensors. So, these are the 2 different application specific criteria that would have to be, where if we are talking about only static sensors where we are going to deploy, these static sensors or if they are pre deployed somehow maybe randomly or whatever how you are going to activate these sensors. So, that you know the application specific criteria are met and if you are talking about a mobile sensor network.

Some of these sensor nodes in these networks as we have seen by definition of mobile sensor network, some of these sensor nodes are mobile and how to plan the trajectory of these mobile sensor nodes. So, these 2 cases are collectively termed as the coverage problem in sensor networks and together they take care of both the static problem and the mobile problem.

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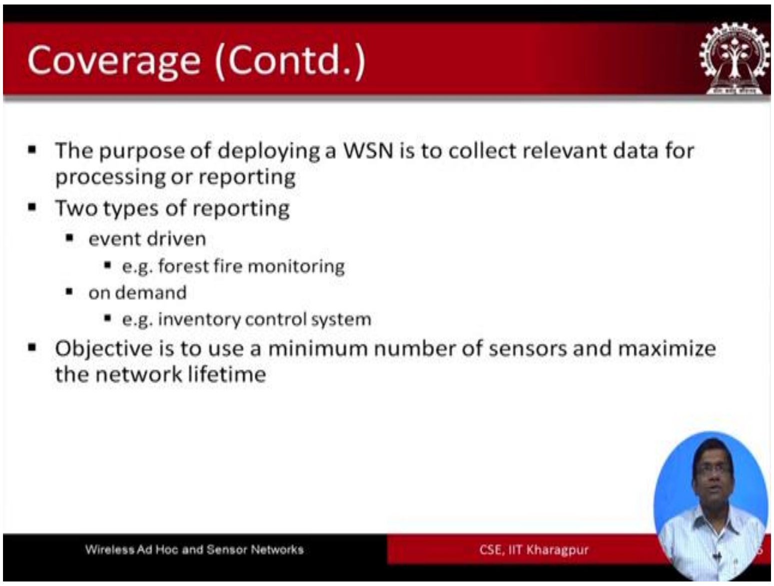

The purpose of deploying is wireless sensor network is to collect relevant data for processing or reporting and there can be. So the data are collected. So, there is some event the sensor nodes they detect that event and the sense and the delay that information to the base station on the sink node.

And that is event driven this is one type of reporting the other type is, for example, what happens in the case of inventory control systems. So, inventory control systems from the sink node of the base station you send a Query and the sensor nodes that are deployed this hint a response back. So, that is on demand on demand a Query is sent and a response is received back. So, the objective is to use a minimum number of sensors and maximize the network like that we do not want. So, we have an area of interest we want to deploy the sensor nodes, we want to have event driven communication, we want to have on demand communication and sensing of the region of interest etcetera. And we want to do it adequately without leaving out any part of the any area or sub area of the network or the region of interest. And how do we do it by reducing the number of nodes that are to be deployed and by ensuring that there is minimized energy consumption and increased network lifetime of the network.

So, lifetime basically there are different definitions of lifetime of a sensor network, there are different definition some definitions talk about that the time until which the first sensor node in the network is going to go down or it is going to run out of it is battery. The other definition talks about the other extreme; that means, the last node is going to die due to the fact that it has done out of it is battery, last node in the network is going to die due to the fact that it has run out of it is battery, and there are some intermediate definitions that are also possible which talks about certain percentage of nodes in the network dying out, due to the exhaustion of energy of the battery in these different nodes of the network.

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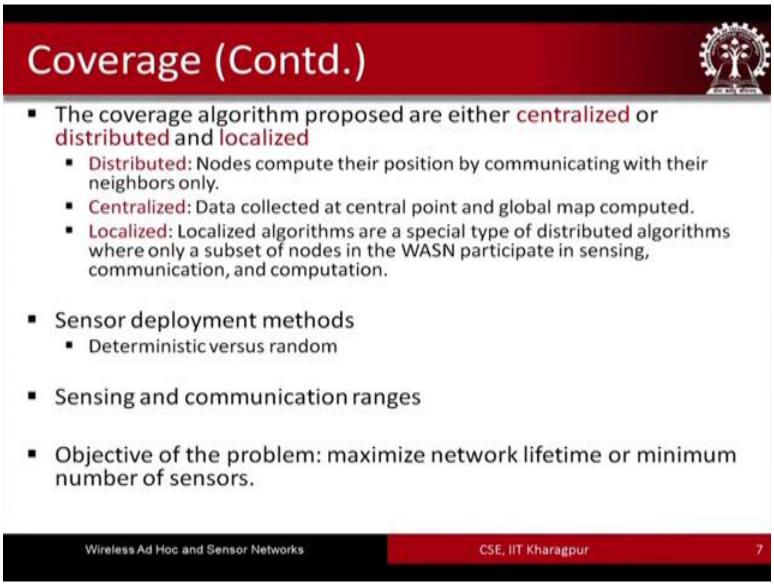

The coverage algorithm proposed are can be of 2 types 3 types. In fact, one is the centralized coverage algorithm.

The second is the distributed coverage algorithm and the third is localized distributed algorithms are the ones, where the nodes basically compute their positions by communicating with their neighbors only. Whereas, in the case of centralized the data are collected at a central point and a global map of the region over which the nodes are deployed is computed centrally by the base stations or something similar. And in the case of localized algorithms you know there is subset of the nodes in the sensor network that participate in the sensing communication and computation, and in it you know in a distributed fashion these nodes they are going to do these computations and determine and ensured coverage of a particular region. There are different methods of sensor node deployment deterministic verses random deterministic deployment means that.

Everything is predefined predetermined you go and x y z, x 1, y 1, z 1, 1 sensor node x 2, y 2, z 2, another sensor node x 3, y 3, z 3, another node x n, y n, z n the n x sensor node. These are already the positions of their sensor nodes are already built (Refer Time: 13:18) planed and they are deployed in a particular in this different specific positions in the region of deployment or interest. A random deployment typically what happens is there is some kind of an ear bone mechanism or something similar it will it is typically ear bone I mean maybe through a helicopter or a Quad copter or something like that. The sensor nodes are basically sprayed in area over which the sensing has to happen sensor activities are have to be executed.

So, these nodes are spread, these are you know they are through ear bone means we are going to be deployed. So, now, what is required is these nodes once they fall onto the ground they have to sense their vicinity the failure you know physical conditions that are occurring around their vicinity. And then they are going to you know pump out the sensed information through them and send to the base station or the control point maybe through multi hop path. So these are the 2 different types of sensor deployments. So, the objective of the coverage problem is to maximize the network lifetime or minimize the number of sensors that are deployed. So, that is the overall objective of the coverage problem.

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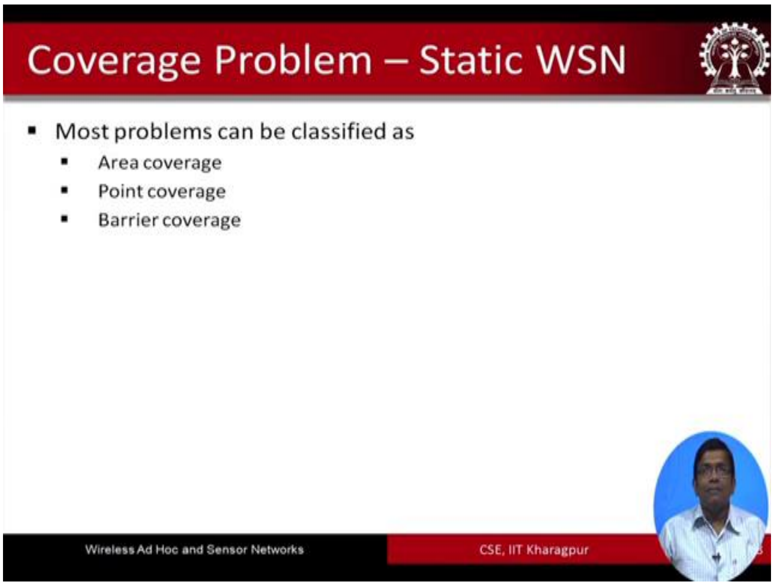

So, the most of the coverage problem in the case of static WSN that (Refer Time: 14:26) static WSN means that all the nodes has classified stationary in these specific WSN implementation. So, if we are talking about you know a WSN implementation where each and every node is stationary.

So, typically the coverage problem can come in 3 flavors. The first one is the area coverage, the second one is the point coverage and third one is the barrier coverage.

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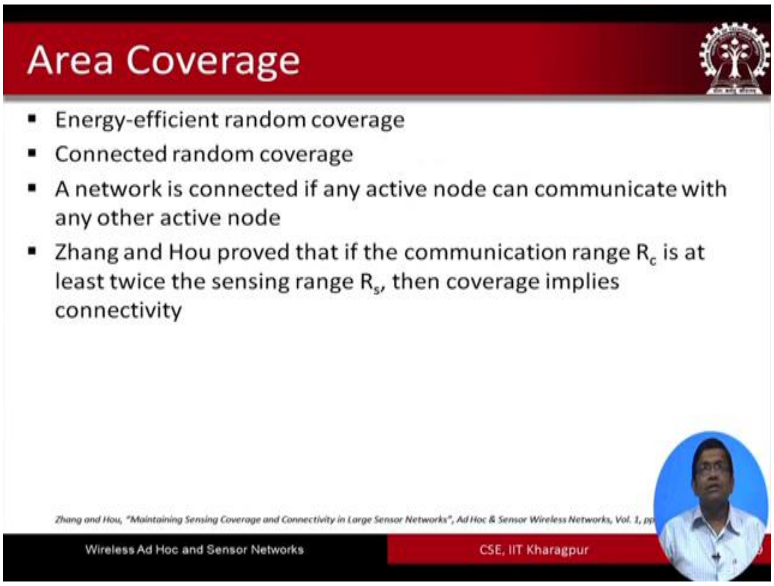

So, we are going to go through each of them shortly. So, area coverage it is a energy efficient random coverage. And a network is connected if you know, where it is required to cover each and every area in a particular you know in a particular region of interest. Some kind of random coverage has to be ensured. So, typically what happens is you know some kind of you know some kind of these nodes are they are deployed and they connect with each other and they have to ensure that each and every point in the area is covered. So, this reference is given.

There is a very important paper which was published in the ad hoc (Refer Time: 16:04) sensor wireless networks in 2005 by 2 researchers of you say, where I mean the researchers the Zhang and Huo. They have proved that if the communication range is at least twice the sensing range then coverage implies connectivity. And this is the result that I have already spoken about in one of the previous slides and this is something that is proven and this proof is there in this particular reference.

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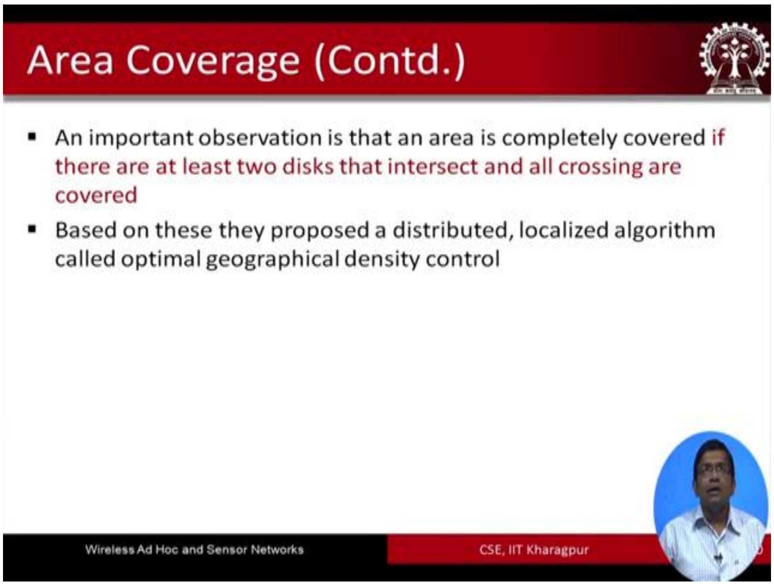

So, an important observation is that in the context of area coverage an important observation is that, an area is completely covered, if there are at least 2 disks that intersect and all crossings are covered. So, this means that it is a circular it is feared in 2D or the circle in sorry this feared in 3D or the circle in 2D around a particular sensor. So, if we are talking about 2D the circle surrounding a particular sensor node. So, that is a disk.

Then when we are talking about a unit disk we are talking about a unit you know, one unit of range or radius of this particular disk right. So we are talking about overlapping of 2 different disks. So this is an observation that was made and this particular result basically appears in this paper that is shown. So, it is stated that an area is completely covered. If there are at least 2 disks that intersect and all crossings are covered and this is based on these. So, based on these the authors that means Zhang and Huo in 2005 in that paper with the reference that was given in the previous slide.

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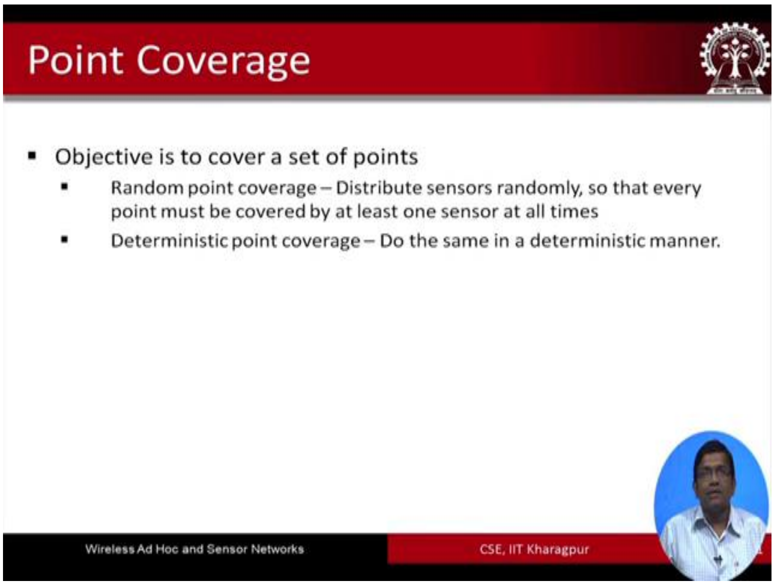

They proposed a distributed localized algorithm called the OGDC the optimal geographic density control algorithm. So, we will try to understand some of these features of this algorithm after a few minutes. Then that is the area coverage; that means, that every area in every point in a part of the area in a region of interest cell to be covered number 1, number 2 is point coverage. So, here what we have is we have a set of points. Instead of so an area is a collection of infinite number of points. So, here we are talking about that in a particular area we have a set of designated points. And in the case of point coverage we are talking about that that those points you know. So, we should deploy the sensor nodes in such a way that those points are covered by at least. So, every point which is of interest has to be covered by at least one sensor node covered by at least one sensor node again means that at least one sensor node should be able to sense.

That particular point it should be within a specific point has to be within the sensing range of a particular sensor node that is a point coverage problem, which again comes in 2 flavors the random point coverage and deterministic point coverage which I am not going to go through, but this is something that is Quite obvious from these names themselves.

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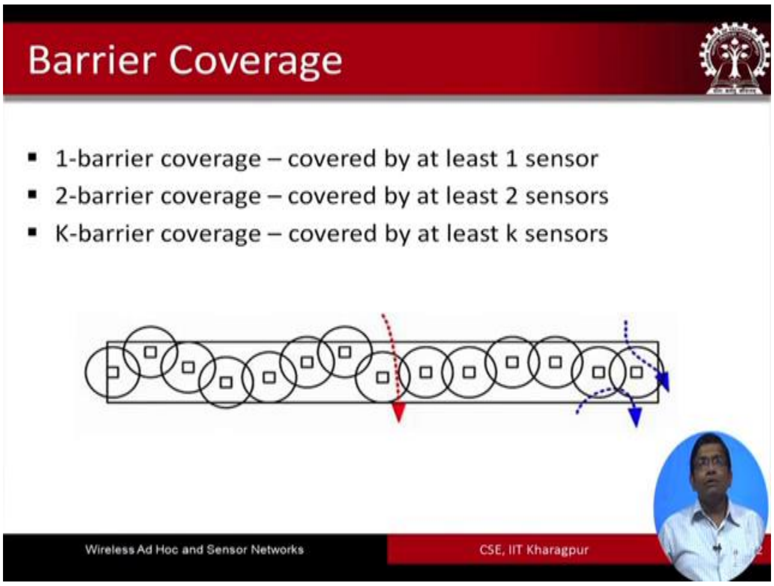

Now, the third flavor is the barrier coverage. So, in the barrier coverage we are talking about that if we have some kind of a barrier, the barrier could be maybe you know let us say that there is a fort. So, in a fort typically what happens is you have these tall you know high walls, and outside the walls typically or outside or inside depending on how you look at it you have some kind of an of a water body right. So, typically you know in the castles in the you know previous times or in the forts and you know palaces etcetera you know this kind of you know architectural styles.

We are available or you know forget about all these. So, it could be because you know. So, you know if you consider a barrier like you know, the areas separating the border; that means, the border between 2 different countries the international border or maybe between 2 different states. So, the state borders and you want to have some kind of a monitoring of what happens across these borders maybe you know it different things. For example, infiltration and infiltration across these borders and so on and so forth. Like you know who are the different intruders that are coming and trying to deploy sensor nodes across these borders and so on. So, this barrier coverage comes into comes very important. So, we have what we have 2 different countries and there is a border between them.

So, we want to deploy the sensor nodes along the border in such a way that there is no person who can come and cross the border without getting detected by at least one sensor node or k sensor nodes depending on the variant of the problem. So, it will be a one coverage problem or a k coverage problem right. So, let us look at the picture in front of us. So in this particular picture we have deployed, this is an example of you know sensor nodes being deployed and what we have are they are deployed the nodes are deployed in such a way that this particular strip or this particular line is every point over here is within the sensing range of at least one node. So, basically you know if we have a trace passer.

So, I mean let us try to understand this particular problem in a different way. Because you know what we are not going to do is unlike in the case of area coverage we are not going to put at every point in this strip, we are not going to put a sensor node. Or we are not going to have every point within the range of a sensor node right. We are not going to do that. So, the problem over here is if somebody wants to cross this border or this barrier, whether it is getting detected by at least one sensor node. So, in this particular example we see that when somebody wants to cross this border it will get detected by at least this sensor node. Or if it changes it is trajectory as well it will there is another sensor node at least which will detect this particular crossing in this particular example what we see that.

It is not crossing the borders, but somebody trying to do like this, right you know. So, it will still get detected by the sensor nodes, but it is not again crossing the border you know. So coming from this region to coming you know through the strip going back to the region itself, and something similar. So what we have we have 3 different forms of barrier coverage one barrier coverage ensures that at least one sensor detects some kind of crossing of the barrier like this. So, at least one sensor it is say 2 barrier coverage talks about at least 2 sensors detecting at or covering at, and k sense k barrier coverage talks about that at least k sensors k number of sensors are able to detect it right.

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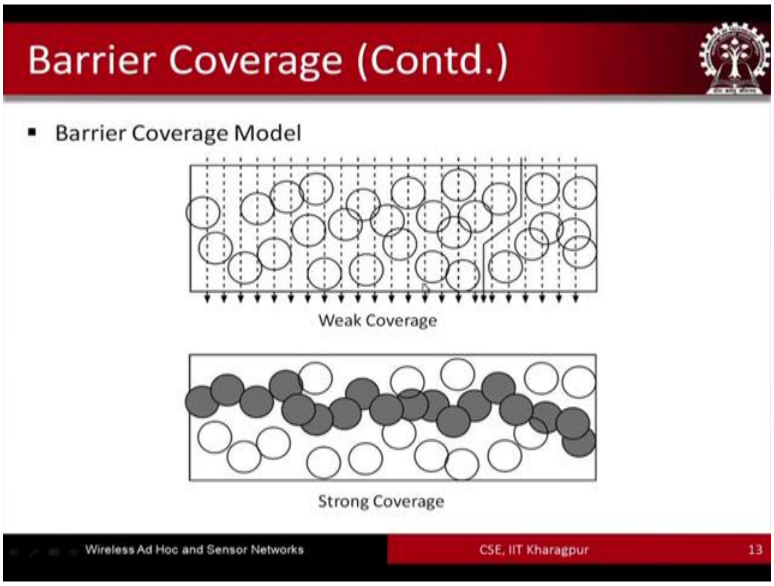

So trying to understand the barrier coverage model even better, so here as we can see over here the sensor nodes, this is the barrier. This strip over here is a barrier. So, here what we see are the sensor nodes are deployed in such a way that there is weaker coverage, because you know somebody who tries to cross this barrier, who take a trajectory like this and be able to cross this barrier without getting detected by even a single sensor node right. So, this particular trajectory if somebody follows then that person is going to cross this barrier without even getting detected by a single sensor node. Otherwise there are other places which where I mean this sort of trajectory, I mean if others take these trajectories like the best arrows over here.

This problem is not there; that means, that it will be there I mean at least there is one sensor node which will detect this kind of crossing of this barriers underneath we see another figure which shows a stronger form of coverage. So, we see that these nodes which are the activated nodes the nodes which are activated. So, these nodes over here anybody trying to cover you know anybody trying to cross will get detected, by at least one sensor node will get detected by at least one sensor node.

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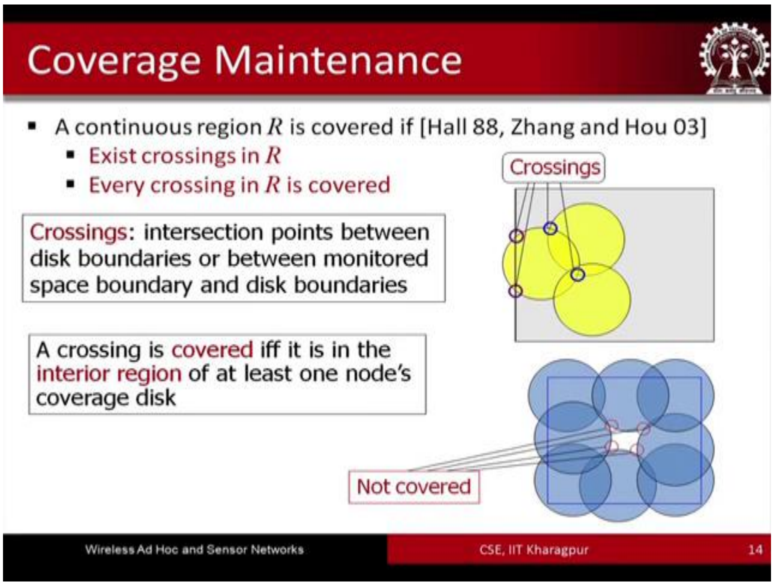

So, let us try to understand some of these concepts. So, the coverage problem as and we are talking about the area coverage problem as explained by Zhang and Huo reads like this that a continuous region R is covered if their exist crossings in R, and every crossing in R is covered. So, what is the crossing? So, this is how what the crossings are pictorially depicted right. So, we have a sensor node we have the disk. So, 2 different sensor nodes with their corresponding disks overlapping over here. So, we get 2 different crossings or the disk basically cutting across the region boundary will give different crossings as well as shown. So, what we have we have multiple crossings. So, there exist crossing is not there, has to be first of all crossings; that means, that there has to be overlap of these different disks and every crossing in R is covered.

And what is the crossing crossings are intersection points between disks boundaries or between the monitored space boundary and this boundaries as I explained before. So, what is required is to cover the crossings. So, Zhang and Hou's work they talk about how to cover the crossings and what is the meaning of covering a crossing. So, we have crossings like shown in this particular figure. So, we have crossings which are covered in this figure. So, for example, this crossing is covered, another crossing is covered, this one, this one and so on, but there are some crossings which are not covered like the ones which is shown in circled in red. So, a crossing is covered even only if it is in the interior region of at least one nodes coverage disk.

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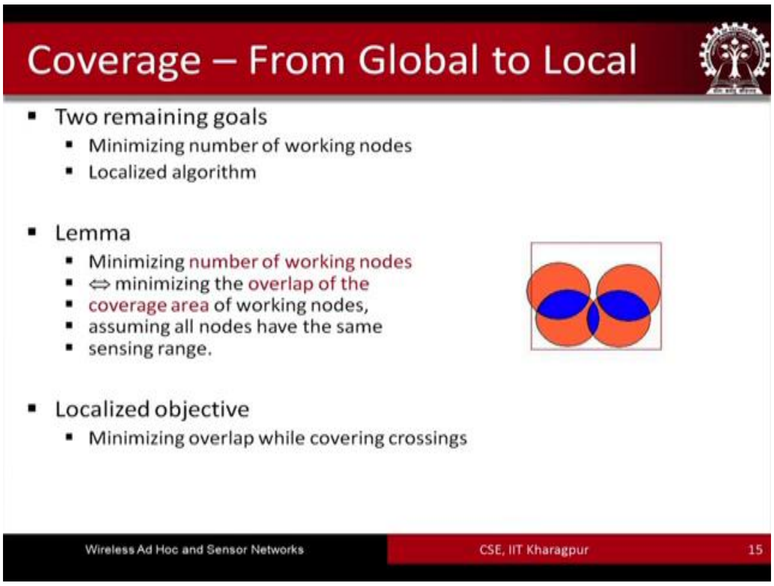

So, there are 2 remaining goals minimizing the number of working nodes and having a localized algorithm for achieving coverage. So, they have proposed different lemmas one lemma talks about that minimizing the number of working nodes.

Is an equivalent problem of minimizing overlap of the coverage area of the working nodes and assuming that all the nodes have the same sensing range? So, the localized algorithm objective is to minimize the overlap while covering the different crossings right.

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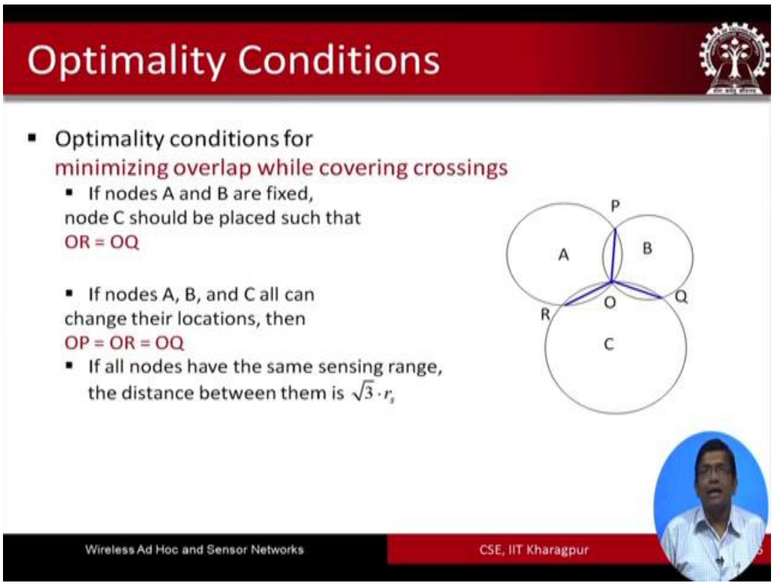

Minimizing these overlaps while covering the crossing. So, there are different optimality conditions that have been. So, when 2 disks A and B and their corresponding you know these disks when they when they overlap. We get crossings and these crossings are marked as P and Q. So, if nodes A and B are fixed node C should be placed node C should be placed in such a way that OR, OR is equal to OQ node C should be placed in.

Such a way that OR is equal to OQ if nodes A B and C all can change the locations then this condition should hold good then OP equal to OR equal to OP equal to OR equal to OQ and if all notes have the same sensing range. So, here we do not see that they have the same sensing range, but it has assumed that they all have the same they are homogeneous in nature and they have the same sensing range then the distance between them is square root of 3 times R's the sensing range.

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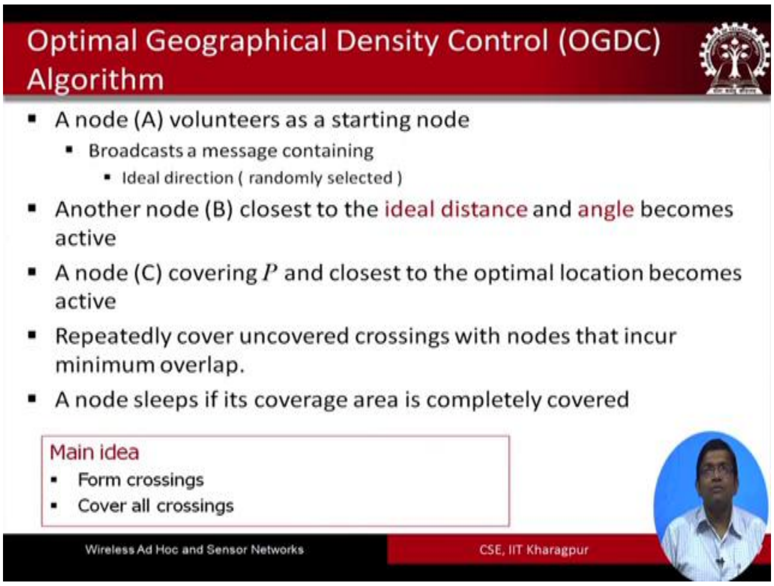

So, the OGDC algorithm has been proposed I am not going to go through it in detail the corresponding reference is there it was proposed by Zhang and Huo in 2005. So, a node a volunteers as a starting node broadcasts a message containing the ideal direction.

And the direction is randomly selected another node B closest to the ideal distance and angle becomes active. A node C covering P and closest to the optimal location becomes active and it repeatedly cover the uncovered crossings with nodes that incur the minimum overlap. And A node sleeps if it is coverage area is completely covered right.

So, the main idea over here is first of all form the crossings and then cover all crossings this is the whole idea of behind the integrities of OGDC algorithm right.

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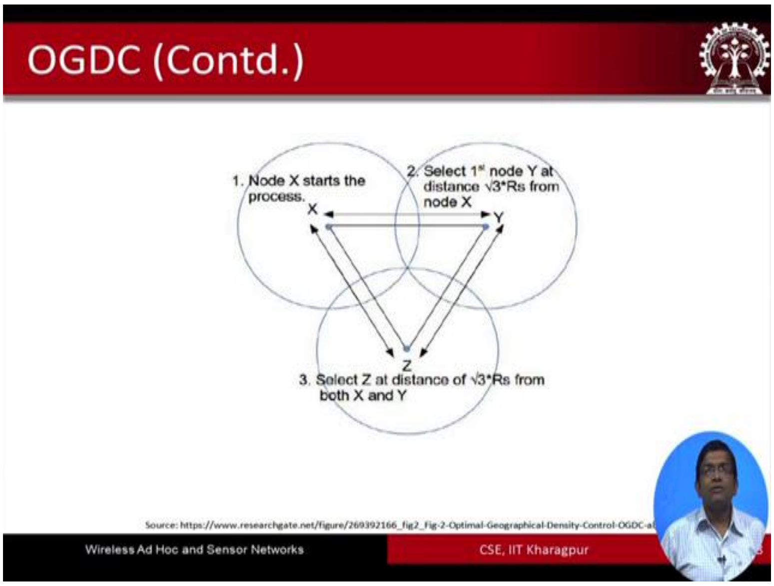

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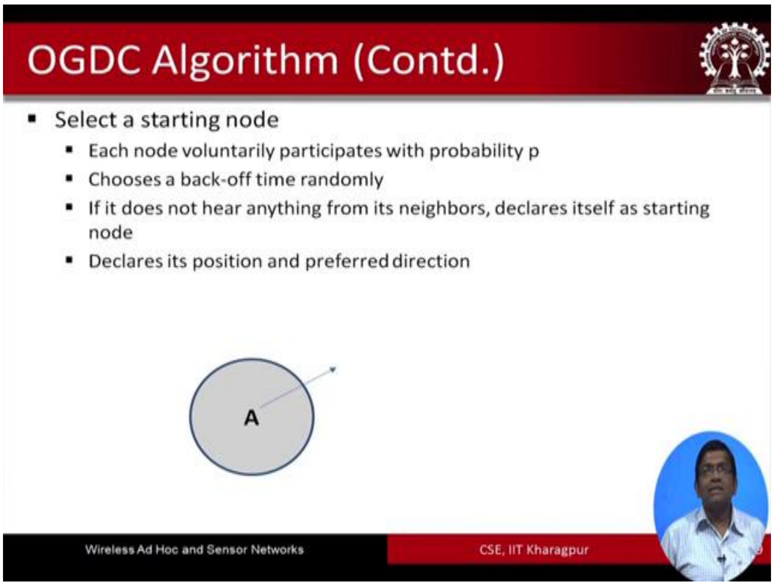

So, we have with respect to this is Quite obvious with respect to what we have seen. So, we start with selecting a node the node voluntarily participates with a probability P to this a back of time randomly, sorry if it does not hear anything from it is neighbors.

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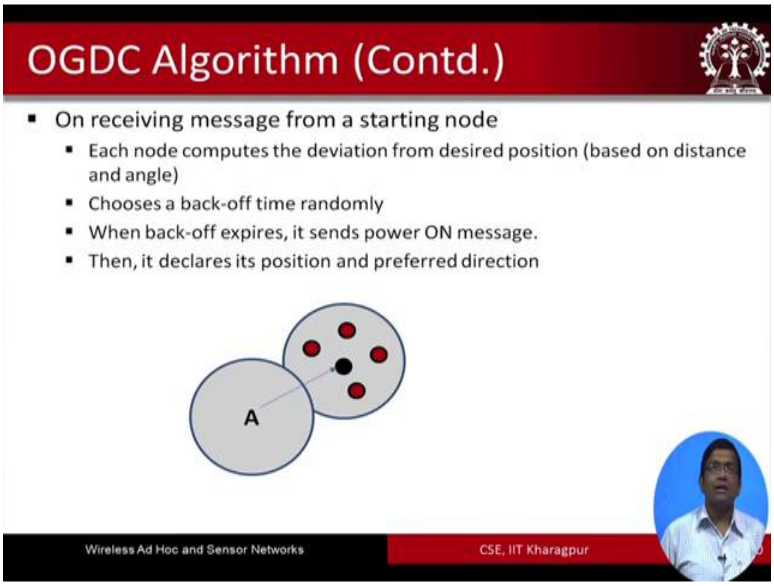

It declares itself as a starting node and declares it is position and the preferred direction like this. On receiving the message from a starting node each node computes the very deviation from the desired position based on the distance and the angles chooses a back of time randomly when the back of time expires, it sends the power on message to the node then it declares it is position and the preferred direction.

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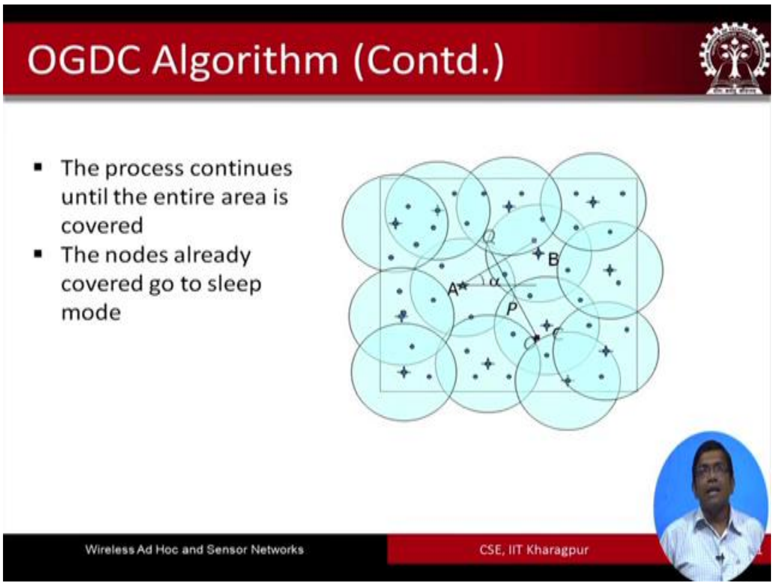

The process continues until the entire area is covered the nodes already covered go to the sleep mode. So, we first cover the nodes which are covered they will go to the sleep mode. So, this is how step by step this happens, whatever we have covered so far. This is how the algorithm works in different steps.

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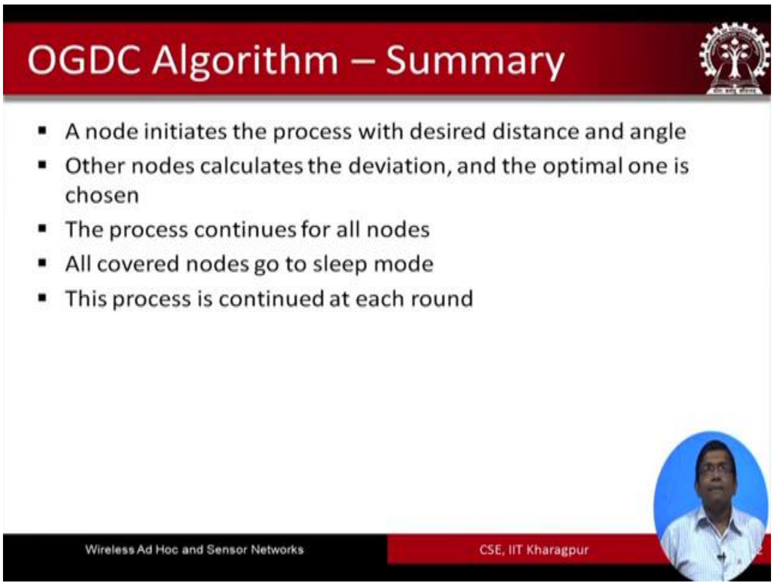

This is the animation of the entire algorithm it is functioning. So, a node in summary OGDC, a node initiates the process with desired distance in angle other nodes calculate the deviation and the optimal one is chosen, the process continues for all nodes and all covered nodes; that means, the nodes which are covered, they will then be sent to the sleep mode and this process is continued at each round.

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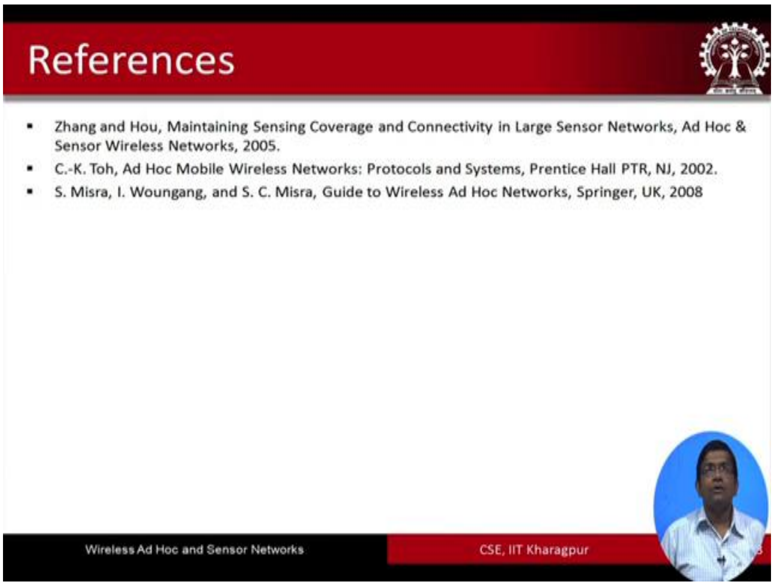

So, this algorithm functions in different routes these are the important references for this particular topic.

Thank you.